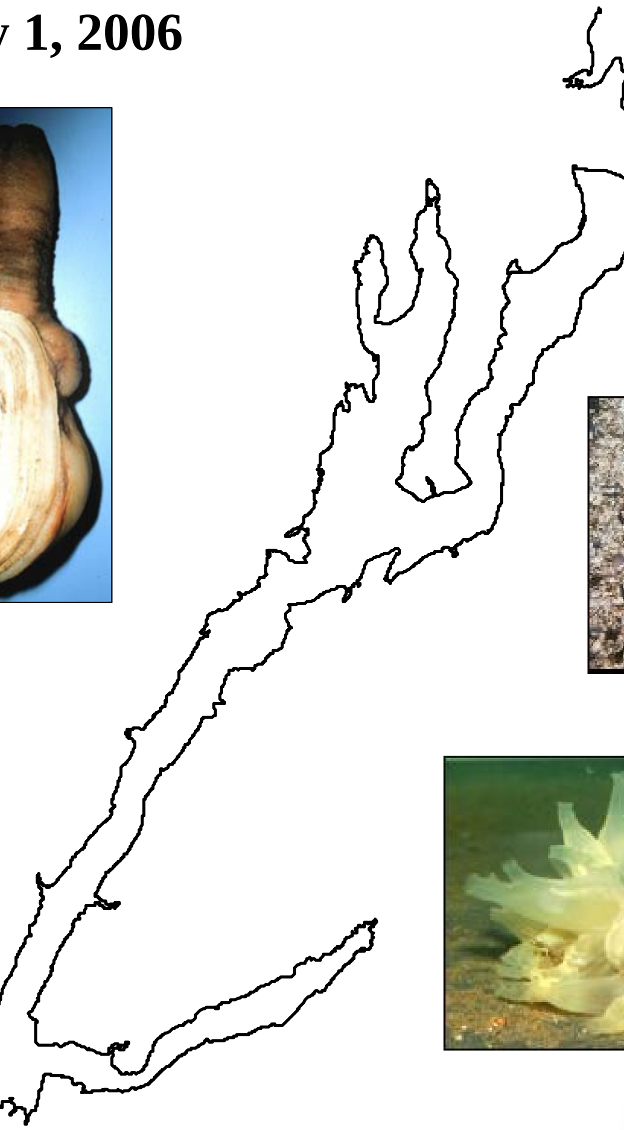
Geoduck Studies in Hood Canal

Progress on Work Associated with House Bill 1896
Report to the 2006 Legislature
House Select Committee on Hood Canal

January 1, 2006



WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

Washington Department of FISH and WILDLIFE

Photos on title page, clockwise from top:
Geoduck (*Panopea abrupta*) photo taken by Don P. Rothaus, Washington Department of Fish and Wildlife (WDFW), Mill Creek, WA.
Dungeness crab (*Cancer magister*) photo taken by Dr. Randy Shuman, King County Department of Natural Resources, Seattle, WA.
Invasive tunicate (*Ciona savignyi*) photo taken by Amy Eko, teacher at A.G. West Black Hills High School, Tumwater, WA

FACT SHEET

Project Title: Geoduck Studies in Hood Canal
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Date of Report: January 1, 2006

Report Funded by: 59th Washington State Legislature
Via Interagency Agreement #IAA 06-61,
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ENACTING LEGISLATION
ENGROSSED SECOND SUBSTITUTE HOUSE BILL 1896

NEW SECTION. **Sec. 1** A new section is added to chapter 79.96 RCW to read as follows: The department shall conduct a study to determine if changes to the geoduck populations in Hood Canal have occurred over time. The department's study shall compare prior population surveys with current surveys conducted as part of this study. The study shall incorporate geoduck beds representative of the northern, central, and southern areas of Hood Canal. No later than January 1, 2006, the department shall submit a report describing the study results to the appropriate committees of the legislature.

NEW SECTION. **Sec. 2** A new section is added to chapter 79.96 RCW to read as follows: The department shall conduct a study to assess the relationship between the Hood Canal's geoduck population levels and environmental conditions, including dissolved oxygen concentrations. To conduct this study, the department shall establish geoduck index stations near the department of ecology's Hood Canal water sampling stations. The index stations shall include stations representative of the northern, central, and southern areas of Hood Canal. No later than December 1, 2007, the department shall submit a report describing the study results to the appropriate committees of the legislature.

NEW SECTION. **Sec. 3** A new section is added to chapter 79.96 RCW to read as follows: The department shall conduct a study to establish an age profile and analyze the shell oxidation rate of Hood Canal geoduck. To conduct this study, the department shall establish sampling stations representative of the northern, central, and southern areas of Hood Canal. No later than December 1, 2007, the department shall submit a report describing the study results to the appropriate committees of the legislature.

NEW SECTION. **Sec. 4** Sections 1 through 3 of this act expire July 1, 2008.

NEW SECTION. **Sec. 5** If specific funding for the purposes of this act, referencing this act by bill or chapter number, is not provided by June 30, 2005, in the omnibus appropriations act, this act is null and void.

Passed by the House March 11, 2005.
Passed by the Senate April 14, 2005.
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1.0 EXECUTIVE SUMMARY

Provisions of House Bill 1896 enacted by the Washington 59th legislature in the 2005 regular session required the Washington Department of Natural Resources (DNR) to conduct a study to determine if geoduck populations in Hood Canal have changed over time. The initial phase of this study included biological surveys of three existing geoduck tracts in Northern, Central, and Southern Hood Canal in 2005. Work was undertaken in the Fall of 2005 to meet the requirements of HB 1896 as a collaborative effort between DNR, the Washington Department of Fish and Wildlife (WDFW), researchers at the University of Washington, and a researcher with the Makah Tribe.

Biological surveys of three previously unfished geoducks tracts (Bridge, Dosewallips, and Tahuya) using standardized stock assessment methods were completed in the Fall of 2005. Estimates of average geoduck density (geoducks/sq.ft.) were made for each of these tracts and compared with two historic estimates for the same areas. A summary of the results follows.

Northern Hood Canal:
On the Bridge tract there is a general trend of density decline between survey years 1986 and 2005, from 0.3865 to 0.0634 geoducks/sq.ft. The decline is significant at the 95% confidence level between the 2005 survey and the previous two surveys. The apparent decline of geoduck density at the Bridge tract is more dramatic than for the entire region in that same time period, and possibly was most severe in recent years. Causal relationships for the decline in density are not known at this time, however observed shifts in substrate types between survey years may have had an effect on geoduck density. The trend on the Bridge tract does not appear to be representative of other geoduck tracts in Northern Hood Canal. Another tract in that area has shown increased density even after harvest.

Central Hood Canal:
On the Dosewallips tract there is an apparent trend of decline in geoduck densities from the 1974 survey to the 2005 survey from 0.0595 to 0.0105 geoducks/sq.ft. At the 95% confidence level the density differences were inconclusive. This tract had no apparent differences in substrate types in survey years, though the tract is steep along the deep margin and it is conceivable that heavy rainfall events or large tidal exchanges could cause dynamic changes in the substrate from time to time.

Southern Hood Canal:
On the Tahuya tract there was a significant decline (at the 95% confidence level) in average geoduck density between the 1978 survey (0.0293 geoducks/sq.ft.) and 1996 survey (0.0021 geoducks/sq.ft.). The low density at Tahuya has not changed significantly between the 1996 survey and 2005 survey (0.004 geoducks/sq.ft.). Even though this tract is along the Tahuya River delta, there were no major differences in substrate types in survey years. The recent establishment of the invasive tunicate, *Ciona savignyi*, may be an indicator of ecological change in this area.

These data from the three tracts indicate varying trends in geoduck populations in Hood Canal. However, given biases and inherent problems noted in this report, the trends may be more related to differences in sampling methods than real changes in geoduck populations. Until several data points using the same standardized methodology are collected, caution should be taken in making comparisons. The results from the surveys of only these three tracts cannot be used to indicate trends in geoduck populations throughout Hood Canal. Surveys from additional tracts are needed to make inferences about sub-regional population trends.

Recommendations for future geoduck surveys include the use of siphon show plots and inclusion of additional unfished areas within each sub-region for comparisons of average tract density estimates. For hydrogeologically active areas, such as the Bridge tract, quantification of substrate types and bathymetry mapping may need to be done to assess these factors in relationship to geoduck populations on the tract. A survey of the distribution of an invasive tunicate, *Ciona savignyi,* is recommended to better understand vertical and horizontal distributions of this animal and its potential impacts to the ecology of Hood Canal.

Continuing work under HB 1896 includes establishment of geoduck index stations in the Central and Southern sub-regions of Hood Canal, aging and analysis of 1162 geoduck shell samples collected in 2005, collection of additional geoduck shell samples in the Southern Hood Canal sub-region in 2006, analysis of oxygen isotopes in 60 water samples collected at two water depths for each geoduck dig site, and analysis of isotopes and trace elements in geoduck shells from each sub-region to reconstruct environmental conditions experienced by geoduck clams over the last several decades.

2.0 INTRODUCTION

2.1 Description of Hood Canal

Hood Canal is a fjord-like blind channel, about 62 miles long, which extends from a convergence of the main channel of Puget Sound with the Strait of Juan de Fuca, southerly along the eastern escarpment of the Olympic mountains. Headwaters of rivers in the Olympic Mountains draining into western Hood Canal receive annual precipitation averaging 79 to 98 inches. In the southern part of Hood Canal annual precipitation averages 59 to 79 inches. Hood Canal is narrow and deep between the mouth to the Great Bend, with maximum water depths exceeding 600 feet near Dabob Bay. Waters become shallow toward the head of Dabob Bay, Quilcene Bay, several smaller embayments, and easterly of the Great Bend. These features result in a unique mix of environmental conditions including weak tidal exchanges, seasonal nutrient loading, and low surface salinities (Johnson, 1997). In addition, a sill at the entrance to the canal impedes the exchange of water, resulting in average resident times for water in Hood Canal of one year or longer (Roberts *et al.* 2005). At times the water is highly stratified which reduces vertical mixing, and contributes to low levels of dissolved oxygen in deeper waters. See Roberts *et al.* (2005) for a detailed history of low dissolved oxygen events in Hood Canal.

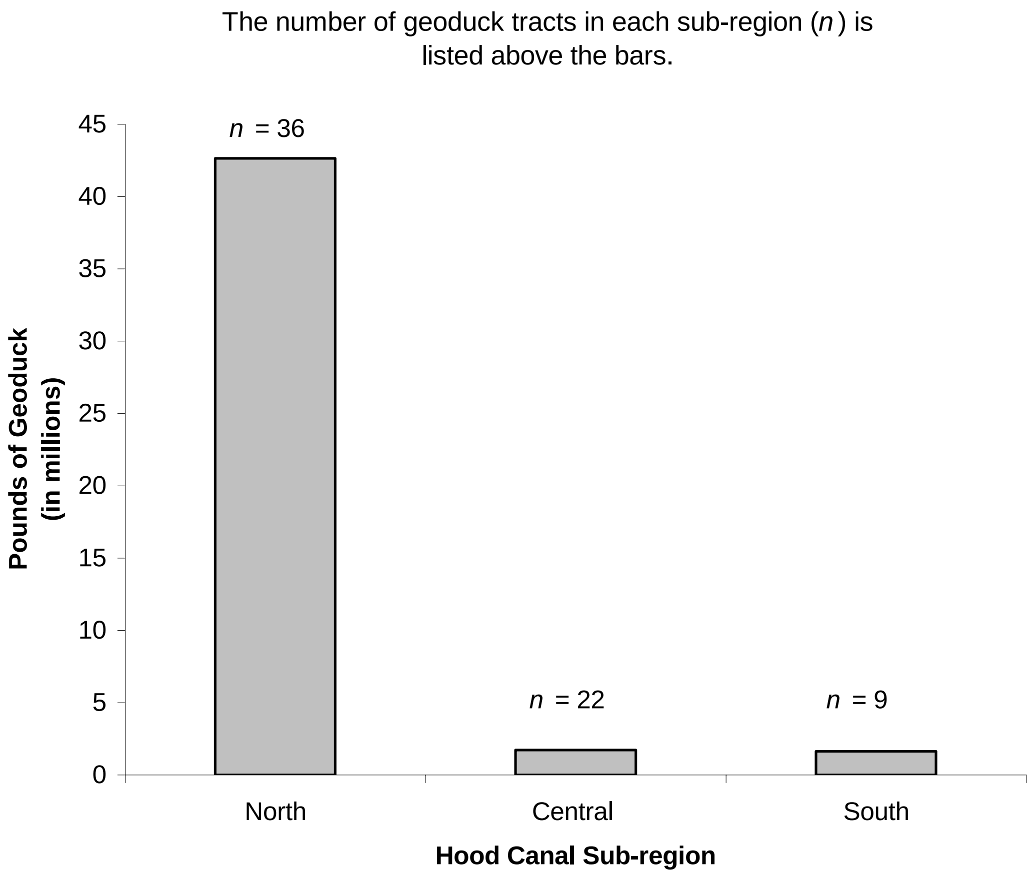
2.2 Description of geoduck clam resources in Hood Canal

Along Hood Canal shorelines, geoduck clams, *Panopea abrupta*, inhabit intertidal and subtidal areas where the substrate (moderate slope and mud and/or sand are predominant substrate types) and other conditions (oxygen rich water and abundant phytoplankton) are favorable. Of about 99,557 acres of surface area in Hood Canal, about 5,165 nearshore subtidal acres, or 5.2%, have received some kind of assessment for geoduck stocks. These assessments have been made over the last 34 years by biologists using scuba gear, and have occurred between the water depths of –18 to –70 feet (MLLW, corrected to mean lower low water). Survey of geoducks using scuba gear below the –70 foot water depth becomes increasingly less efficient due to bottom time constraints. There is little known about the stock structure of deeper water geoducks, or their contribution to the spawning biomass.

The estimated geoduck biomass for Hood Canal in 2004, based on surveyed areas, is about 46,019,000 pounds. The Northern sub-region of Hood Canal (defined below in section 3.1.1) encompasses about 36,780 acres, or 36.9% of the total Hood Canal area, yet contains about 42,650,000 pounds of geoducks biomass, or 92.7% of the total geoduck biomass estimate for Hood Canal (Figure 1). The Central sub-region of Hood Canal encompasses about 43,319 acres (43.5% of total area) and contains about 1,736,000 pounds of geoduck clam biomass

(3.8% of total geoduck biomass). The Southern sub-region of Hood Canal encompasses about 19,459 acres (19.5% of total Hood Canal area) and 1,633,000 pounds of geoduck biomass (3.5% of total Hood Canal geoduck biomass).

Figure 1. Estimated Geoduck Biomass on surveyed tracts from the 2004 Atlas by Sub-Region in Hood Canal



2.3 Study proposals

Under Engrossed Second Substitute House Bill 1896, three studies will be conducted: 1) Changes in geoduck populations over time; 2) Index station establishment; and, 3) Age profile and chemical analysis of geoduck shells.

2.3.1 Changes in Geoduck Populations over Time

Changes to geoduck populations over time will be determined by comparing prior population surveys with new surveys conducted under this proposal. To gauge recent changes in the geoduck populations in Hood Canal, geoduck tracts with good population estimates should be surveyed again. Significant changes in geoduck densities can be determined more reliably when the prior (baseline) transects number 30 or more. Tracts which only have a few transects will have a high variance resulting in conclusions with relatively high uncertainty. A decline in geoduck density on the tracts may indicate a decline in the health of the ecosystem. Surveys of these same tracts in future years may give an indication of changes in geoduck populations caused by environmental conditions over time. The focus of this report is to provide results of the preliminary geoduck density surveys.

2.3.2 Geoduck Index Stations

To assess relationships between geoduck population trends in Hood Canal and changes in environmental conditions, geoduck index stations will be established near existing Washington Department of Ecology (Ecology) water monitoring stations. Three to five discrete locations in Hood Canal should be selected for tagging geoducks and re-visiting in future years to determine population trends. Then correlations can be made between geoduck density data collected at index plots (stations) and marine water quality data collected at Ecology water monitoring stations. The index stations would have more utility than standard surveys, because the locations could be chosen in close proximity to established Ecology water monitoring stations and the precision of the estimates can be better controlled (by taking a complete census of geoducks within a small defined area). If environmental conditions change in Hood Canal, the index stations may be good biological indicators of this change.

2.3.3 Geoduck Aging and Chemical Analysis

Geoduck aging and shell chemical analysis are very important to studies correlating Hood Canal geoduck population parameters with environmental conditions. Geoducks can be aged from growth layers in their shells (termed annuli), similar to growth rings found in trees. The growth information collected from geoduck shells can be used to compare good growth years with poor growth years. Some researchers have linked geoduck growth with environmental conditions such as sea temperatures and the influx of river discharge (fresh water) into marine waters. If the geoduck sample size is large, the favorable years for geoduck recruitment (larval settlement and survival) may be evident and may also be correlated with important environmental parameters. Another benefit of this study is that the natural mortality population parameter can be estimated from this age frequency data.

To better understand low dissolved oxygen effects in Hood Canal, large samples of geoduck clams will be taken from the Northern, Central, and Southern sub-regions of the Canal at various water depths in close proximity to Ecology water monitoring stations. Aging these samples will allow analysis of relationships between geoduck growth and recruitment with certain environmental parameters including dissolved oxygen. Using cross-validation techniques, geoduck growth patterns may be reconstructed for prior decades.

Using the same geoduck shell samples collected in the age frequency study, chemical analysis will be done to provide a more direct estimate of low dissolved oxygen levels experienced by geoduck clams over time. Researchers have used micro-milling techniques to sample fish otoliths (a calcium carbonate structure found in inner ears of teleost fish) to study ratios of stable carbon and oxygen isotopes to infer climatic changes. This work has also been done on some freshwater and marine bivalves. The concentrations of iron, magnesium, and other metals incorporated in the shell matrix may also provide reliable indicators of low dissolved oxygen. To date there have been no attempts to use the chemical composition of geoduck shells to infer ecological changes. This study may provide information to detect long-term changes in the Hood Canal ecosystem and possibly stock structure of geoduck clams on a small geographic scale.

3.0 SURVEY METHODS

3.1 Criteria for selecting geoduck tracts surveyed in 2005

Five criteria were used for selecting geoduck tracts surveyed in 2005; 1) At least one tract in each Hood Canal sub-region (Northern, Central, Southern); 2) In close proximity to established Ecology marine water monitoring stations; 3) No prior geoduck clam harvest on the tract; 4) At least two prior surveys completed; and 5) A high level of survey intensity, relative to other tracts in the sub-region for the time frame being compared. These criteria serve to coordinate and optimize the information gathered during biological surveys with water monitoring stations and other on-going and future studies. These criteria also serve to maximize the chance of detecting differences in geoduck density between geographic regions of Hood Canal and over time.

3.1.1 Regions – Northern, Central, and Southern Hood Canal

Pursuant to Engrossed Second Substitute House Bill 1896, operational definitions for three sub-regions of Hood Canal were established for Northern Hood Canal, Central Hood Canal, and Southern Hood Canal. These sub-regions can be described partly by existing WDFW Marine Fish/Shellfish (MF/SF) Management and Catch Reporting Areas [defined in Washington Administrative Code (WAC), 220-22-400]. For purposes of this study, the Northern Hood Canal sub-region includes all of MF/SF Area 25C and that portion of 27A east of a line projected from Oak Head to Misery Point; Central Hood Canal is that portion of MF/SF Area 27A west of a line projected from Oak Head to Misery Point and also MF/SF Area 27B, and South Hood Canal is MF/SF Area 27C (Figure 2).

3.1.2 Proximity to Ecology water monitoring stations

A second criterion for selecting the study sites (geoduck tracts) was close proximity to existing Ecology water monitoring stations in Hood Canal (Figure 3). Ecology has two types of monitoring stations, core and rotating. Core stations are permanent stations that are sampled at least every year and rotating stations are sampled in fewer years, and may also have fewer sample dates within a year. In the Northern Hood Canal sub-region a core station is located near King Spit/Bangor (#HCB006) and a rotating station located within Port Gamble Bay (#PGA001). In the Central Hood Canal sub-region there are no core stations established. A rotating station is located near Point Whitney at the mouth of Dabob Bay (#HCB002) and a second rotating station is located near the Hamma Hamma River (#HCB003). In the Southern Hood Canal sub-region a core station is located near Sisters Point (#HCB004) and a rotating water station is located in Lynch Cove (#HCB007).

Figure 2. Hood Canal Sub-Region Boundaries

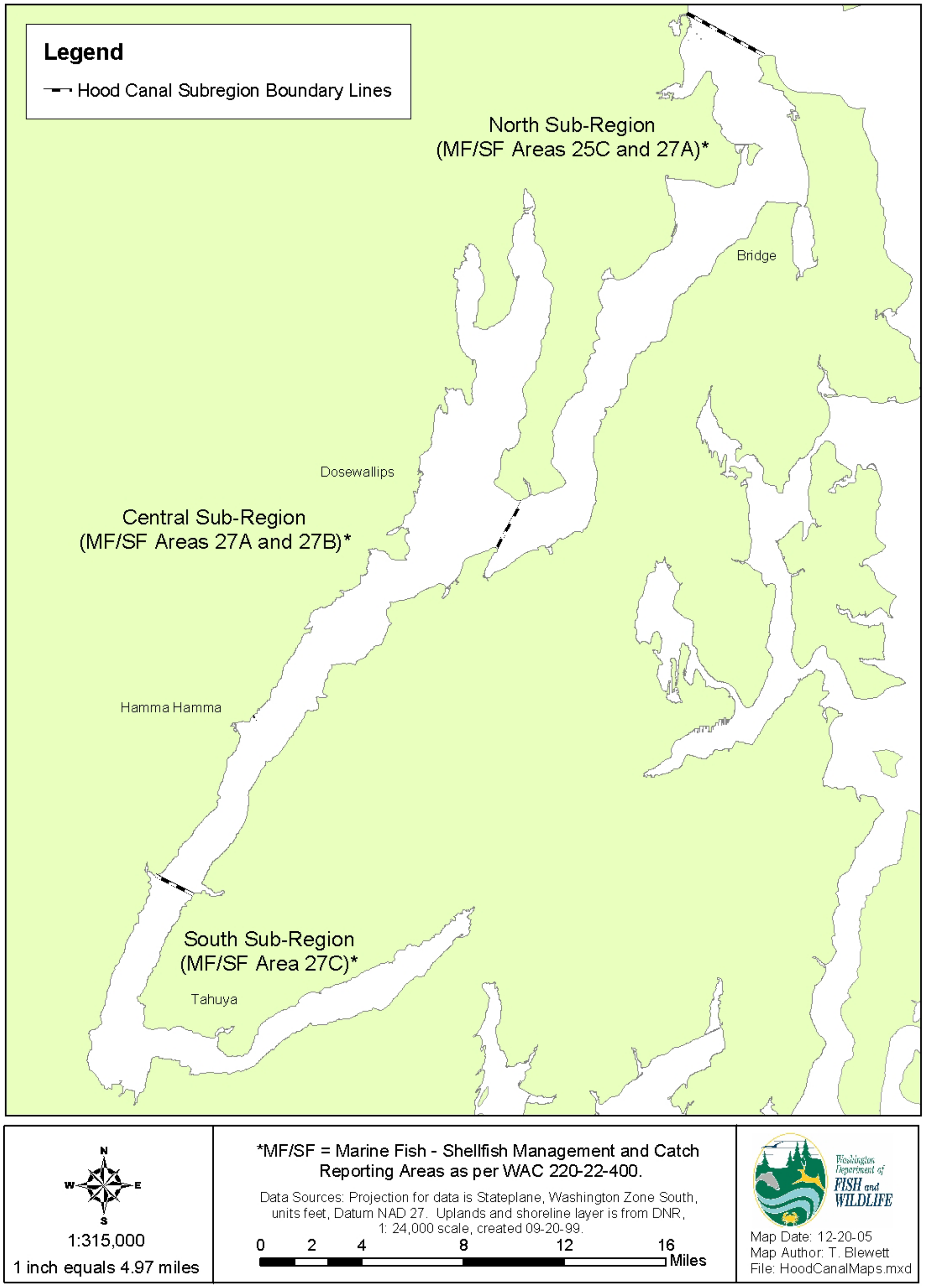


Figure 3. Geoduck Study Sites for the Hood Canal Low Dissolved Oxygen Project

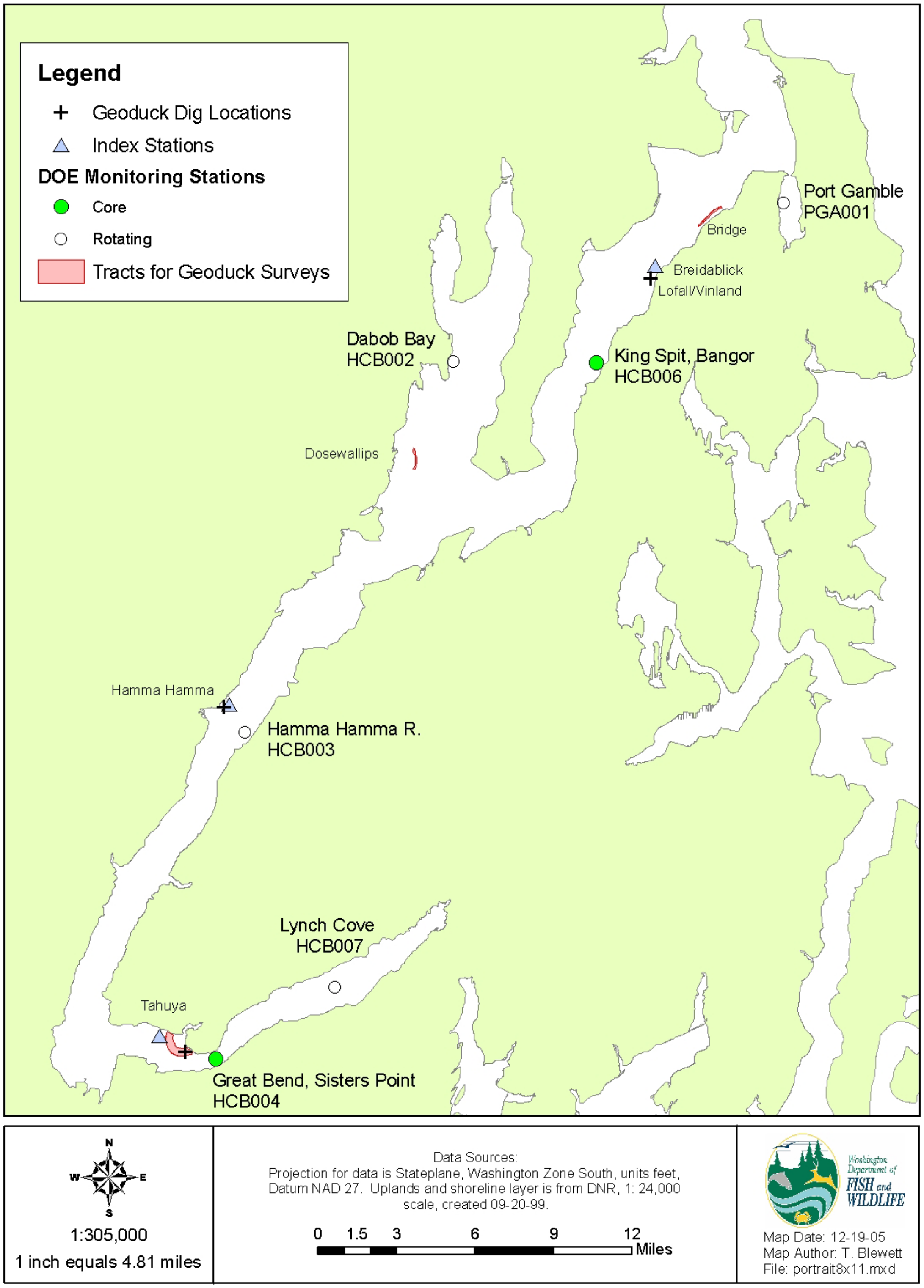
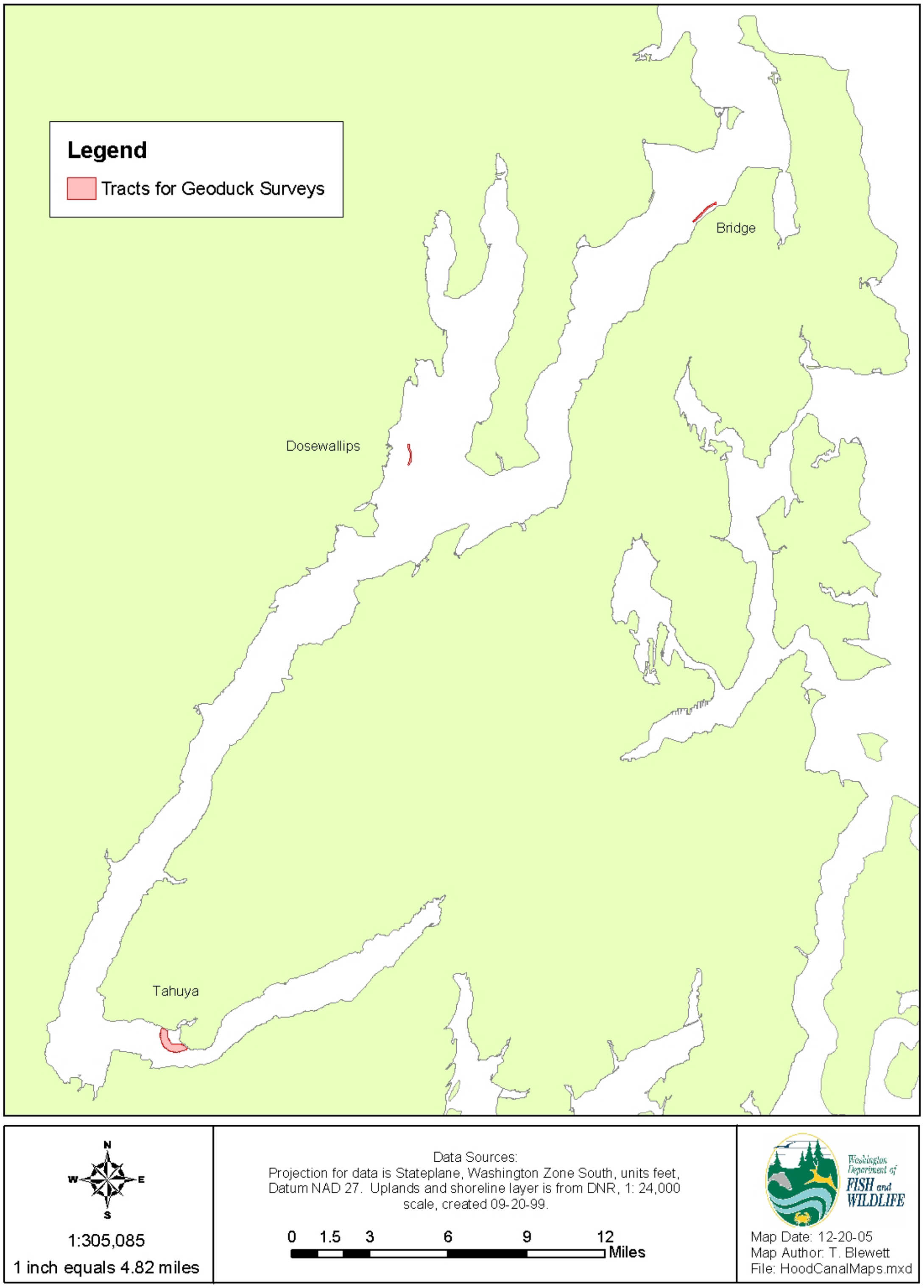


Figure 4. Geoduck Survey Sites for the Hood Canal Low Dissolved Oxygen Project



3.1.3 Areas where geoduck harvest has not previously occurred

To determine changes in geoduck density over time, which may be attributed in part to a balance between natural mortality (decline in density) and recruitment (increase in density), it is desirable to control for mortality from other sources (such as fishing mortality). In order to eliminate harvest as a source of mortality, only tracts that did not have prior commercial harvests were considered.

3.1.4 Prior surveys on tracts

To compare changes in geoduck density over time, it is necessary to have data from previous surveys. Prior to 2005, certain tracts in Hood Canal had previous surveys in two or three different years, beginning in the early 1970s. To maximize both the span of time and trend of the data, a criterion of two prior surveys was used to select potential tracts.

3.1.5 Sufficient survey intensity

Another consideration for selecting the geoduck tracts is intensity of previous surveys. Variability in survey data tends to decrease as the survey intensity (number of transects) increases. A cursory survey of an area to determine the presence or absence of a geoduck bed will likely have high variability and low resolution in an analysis. Further it is desirable to have survey intensity similar from year-to-year, to control for variance. The tracts selected have seven or more transects per tract for each survey year. In recent years, a survey intensity threshold has been established at +/- 30% of the mean (average) biomass estimate for a tract at the 95% confidence level.

3.2 Description of geoduck tracts selected

ESSB 1896 requires that samples be collected from the northern, central and southern portions of Hood Canal. One tract from each of the sub-regions was selected based on the criteria provided in Section 3.1.

In Northern Hood Canal the Bridge geoduck tract (#20650) was selected for a survey in 2005 (Figures 3 and 4). This tract met the tract selection criteria and is also in close proximity to the only geoduck siphon “show” plot currently established in Hood Canal, near the community of Breidablick (described in more detail in 3.4). The Bridge geoduck tract is also located between a core water quality monitoring station at King Spit (#HCB006) and a rotating water quality station in Port Gamble Bay (#PGA001). For purposes of this study, the Bridge geoduck tract covers about 67 acres of subtidal land between the –18 to – 70 foot

(MLLW) water depth contours. The tract was first surveyed by WDFW in 1986 with 12 transects, and resurveyed in 1995 with 25 transects. This tract is currently ranked 9th highest out of 36 tracts in Northern Hood Canal for average geoduck density (Table 1).

Table 1. Density estimates from the 2004 Atlas for geoduck tracts in Northern Hood Canal.

Ranked by Density (Highest to Lowest in the Sub-Region)
Northern Hood Canal Sub-region

Tract Number	Tract Name	Rank within sub-region	Average Number of Geoducks/Sq.Ft.
20000	Port Gamble	1	0.52
20050	Port Gamble Polluted	2	0.45
19750	Foulweather 2	3	0.43
20600	Hood Canal Bridge	4	0.42
19150	Port Ludlow	5	0.38
19600	Twin Spits	6	0.28
20200	Hood Head East	7	0.28
20020	Point Julia	8	0.26
20650	Bridge	9	0.26
19650	Foulweather	10	0.24
20800	Brown Point	11	0.24
19900	Coon Bay 1-4	12	0.22
20250	Hood Head South	13	0.21
20750	Vinland	14	0.19
19350	Tala Point	15	0.17
19400	Tala Point South	16	0.17
19550	Foulweather Bluff	17	0.17
21000	Hazel Point	18	0.16
20550	Thorndyke	19	0.11
19700	Foulweather 1	20	0.10
20100	Port Gamble Inside	21	0.10
19300	Colvos Rocks East	22	0.09
21150	Bangor-Trident	23	0.09
19000	Snake Rock N.	24	0.08
20900	Brown Point South	25	0.08
21350	Olympic View	26	0.08
21450	Warrenville (Big Beef)	27	0.08
20450	Case Shoal South	28	0.07
20700	Lofall	29	0.07
19450	Point Hannon	30	0.06
20300	Sisters/Shine	31	0.06
20400	Case Shoal	32	0.06
21200	King Spit	33	0.06
19100	Snake Rock	34	0.04
19200	Colvos Rocks	35	0.03
20500	South Point	36	0.03

In Central Hood Canal the Dosewallips tract (#22250) was selected for a survey in 2005 (Figures 3 and 4). This tract met the selection criteria (described above) to be included in this study. The Dosewallips tract is near the Dabob Bay water monitoring station (#HCB002). This tract is currently ranked 3rd highest out of 22 tracts in Central Hood Canal for average geoduck density (Table 2). The Dosewallips tract also covers a larger area (about 20 acres) and has more transects on the second survey than the two higher density tracts in the Central Hood Canal sub-region, Duckabush tract (#22700) and Ayock Point tract (#22900). Tracts in this sub-region with lower densities than Dosewallips would have been difficult to survey in the Fall of 2005, due to low siphon show factor. Also, seventeen out of nineteen lower density tracts did not meet the criteria for inclusion in the survey. The Dosewallips tract was first surveyed by WDFW in 1974 with 7 transects, and resurveyed in 1998 with 20 transects.

Table 2. Density estimates from the 2004 Atlas for geoduck tracts in Central Hood Canal.

Ranked by Density (Highest to Lowest in the Sub-Region)
Central Hood Canal Sub-region

Tract Number	Tract Name	Rank within sub-region	Average Number of Geoducks/Sq.Ft.
22700	Duckabush	1	0.23
22900	Ayock Point	2	0.17
22250	Dosewallips	3	0.06
22350	Stavis Bay	4	0.05
22650	Quatsap Point	5	0.05
21750	Broadspit	6	0.04
22450	Tekiu Point	7	0.04
21800	Red Bluff	8	0.03
22100	Cedric's Beach	9	0.03
22850	Hamma Hamma	10	0.03
21650	Camp Discovery	11	0.02
22800	Triton Head South	12	0.02
21500	Oak Head	13	0.01
21700	North Dabob	14	0.01
22400	Hoodpoint	15	0.01
22550	Anderson Cove Recovery Bed	16	0.01
23000	Chinom Point	17	0.01
21550	Zelatched Point	18	0.00
21600	Tabook Point	19	0.00
22150	Jackson Cove	20	0.00
22200	Wawa Point	21	0.00
22300	Seabeck	22	0.00

In Southern Hood Canal there are only 9 tracts with survey data. The preliminary surveys done in 1971 were very cursory with only one to three transects completed per tract. Two tracts, Musqueti Point (#23500) and the Tahuya tract (#23550) received additional transects in 1978, though only the Tahuya tract (Figures 3 and 4) meets the selection criteria (described above) to resurvey in 2005. The Tahuya tract is currently ranked last in Southern Hood Canal for average geoduck density (Table 3). The Tahuya tract is in close proximity to the Great Bend, Sisters Point water monitoring station (#HCB004). The Tahuya geoduck tract covers about 241 acres of subtidal lands. The Tahuya tract was first surveyed in 1971 with five transects, then in 1978 with nine transects, and then resurveyed in 1996 with 52 transects. Due to the low number of transects in 1971, comparison of mean densities for Tahuya include data collected in 1978, 1996, and 2005.

Table 3. Density estimates from the 2004 Atlas for geoduck tracts in Southern Hood Canal.

Ranked by Density (Highest to Lowest in the Sub-Region)
Southern Hood Canal Sub-region (with notes below about survey intensity)

Tract Number	Tract Name	Rank within sub-region	Average Number of Geoducks/Sq.Ft.
24000	Sisters Point	1	0.07
23600	Union	2	0.06
23100	Lilliwaup	3	0.04
23500	Musqueti Point	4	0.03
23700	Union East	5	0.03
23200	Hoodsport	6	0.02
23250	Annas Bay	7	0.02
23800	Hood Canal South End	8	0.01
23550	Tahuya	9	0.00

Survey Years and Number of Transects

24000	Sisters Point	1971-2 transects
23600	Union	1971-3 transects
23100	Lilliwaup	1971-2 transects
23500	Musqueti Point	1971-1 transect;1978-5 transects
23700	Union East	1971-3 transects
23200	Hoodsport	1971-2 transects
23250	Annas Bay	1971-2 transects
23800	Hood Canal South End	1971-2 transects
23550	Tahuya	1971-5 transects;1978-9 transects; 1996-52 transects; 2005-74

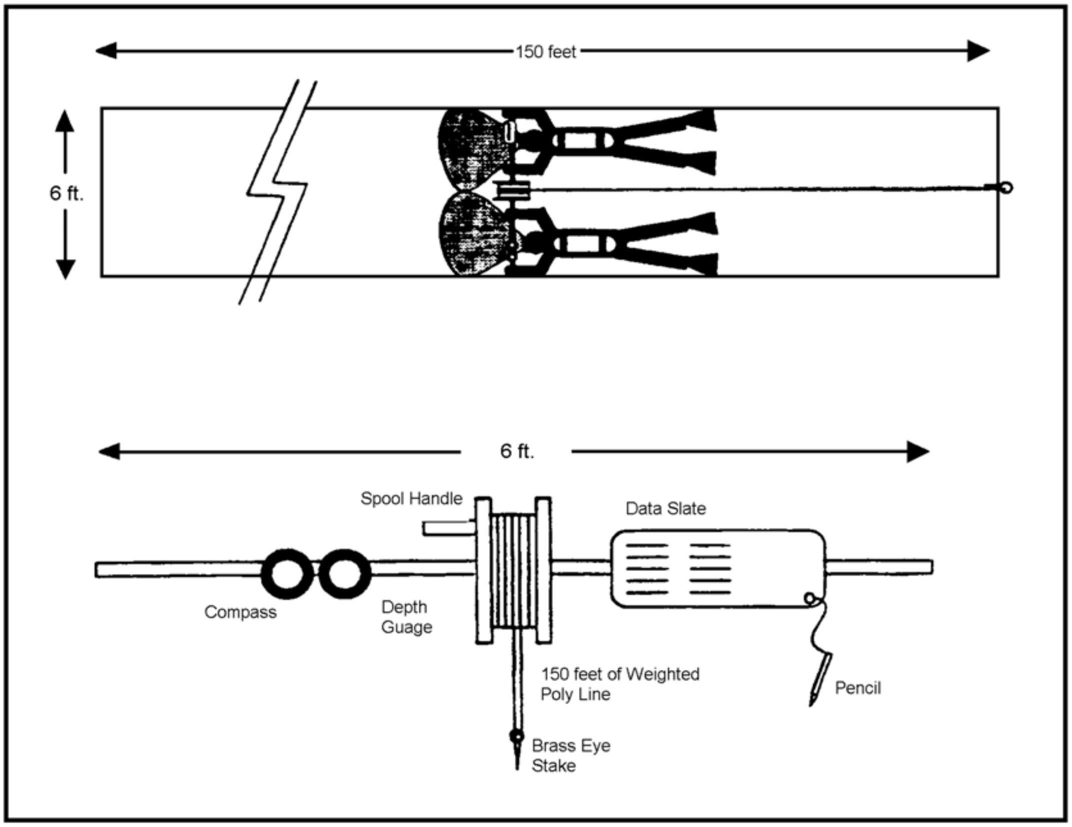
3.3 Standard geoduck surveys

Biological surveys of the Bridge, Dosewallips and Tahuya geoduck tracts (Figure 4) were conducted by WDFW in 2005 according to standard methods (Bradbury *et al.,* 2000). These methods were developed to provide managers with geoduck stock assessment needed to recommend total allowable catch (TAC) within major geographic regions of Puget Sound, such as Hood Canal. The current methods include defining a relatively small subtidal survey area, termed "tract." Tracts are normally confined to water depths equal to or deeper than –18 feet (corrected to mean lower low water) and shallow of the -70 foot water depth. "Side" boundaries of tracts may be defined by benthic conditions encountered during the survey such as steep slopes or substrates which hinder geoduck digging (such as cobble or shell), biotic conditions such as low geoduck density, physical barriers such as ferry docks and marinas, security buffers for military facilities and passenger vessels, and for harvest management purposes to optimize harvest operational area or to increase the number of units for harvest rotation.

The sample unit is a standard geoduck belt transect, which is 6 feet wide and 150 feet long, for a total area of 900 sq.ft. (Figure 5). A transect spool is used to measure transect width and length. Additional instruments and an underwater data slate allow divers to observe and record water depths, compass bearings, substrate types, and biological data. The sample design uses a random starting point along the nearshore tract boundary (-18 foot contour, corrected to MLLW). Divers using scuba gear begin at the random start point and swim seaward across the water depth contours, perpendicular to the shoreline, or on a modified "oblique" angle when a tract is narrow and the objective is to maximize diver "bottom time." It is desirable to swim across water depth contours, since geoduck density usually changes with depth.

The start position of each transect is recorded using Global Positioning System (GPS) instruments on the dive vessel, which hovers over the diver bubbles. At the end of each transect, divers record data such as substrate types and composition, number of geoduck siphons observed within the transect, transect water depths (which are later corrected to MLLW), the presence of other marine animals and plants, and other noteworthy observations (such as derelict gear depths and locations). Divers continue with additional transects until the –70 foot (gauge) water depth is reached. At that point, divers turn toward shore on a predetermined compass course when using oblique transect lines and continue with transects to the –18 ft (MLLW) contour, or for transects perpendicular to the shoreline, divers end the transect at or near the –70 foot water depth contour and then surface from the dive. Once a transect line is completed, a new transect line is started within the tract and farther along the shoreline, about 1000 feet from the first line. For irregular shorelines or complex bathymetry, *ad hoc* sampling methods are sometimes needed to obtain a representative sample of the geoduck population on a tract.

Figure 5. Geoduck Transect Spool and Transect Dimensions



Adapted from "Stock Assessment of Subtidal Geoduck Clam (Panopea abrupta) in Washington," (Bradbury *et al*., 2000).

A standard geoduck survey normally includes digging a random sample of ten geoducks from one out of every six transects completed. The dig samples provide an estimate of average weight of geoducks on a tract. These data are not a critical component of this project. This study examines the change in geoduck density over time and between locations, as an indicator of population change. A weight sample from prior surveys is not one of the tract selection criteria. A practical reason for this is that many tracts in Hood Canal do not have average weight estimates. In fact, until 2005, none of the tracts in Southern Hood Canal have site-specific average weight estimates. Weight samples have not previously been taken on these southern tracts due to the low density of geoducks noted on the initial survey. Instead, a Puget Sound average weight of two pounds was used to obtain a rough estimate of biomass for these tracts. Since the Puget Sound average weight is only a rough approximation of the true site-specific average weight for a tract, it is not a factor that can be used in the scope of this study.

Geoduck surveys were not always standardized. During initial surveys in the 1970's, only a few transects may have been done to see if a tract might have commercial potential. If a tract did not have a likelihood of being commercially harvested in a reasonable time frame, then additional survey effort was not expended, and no weight samples were collected. In addition, tracts were surveyed to –60 ft (MLLW) during many of the earlier surveys, especially pre-1990. These factors must be considered when comparing surveys from year to year.

3.4 Correction of geoduck transect counts with a siphon "show" factor

Subtidal geoduck clams are buried up to 3 feet in the substrate and are only visible to divers when their siphon tips are near or above the substrate surface. Geoducks tend to "show" better from Spring to early Fall when plankton is more available and they are actively feeding (actively pumping water through their siphon). Counting only visible siphon shows will bias the true population estimate by underestimating geoduck density. To correct for this bias, a standard geoduck show plot should be established (Bradbury *et al*., 2000).

Show plots are standardized delineated subtidal areas (usually the same dimensions as a standard transect, 900 sq.ft.) that are located near tract survey sites and represent conditions on the tracts. The "true" population of geoduck clams within a show plot is determined by flagging ("tagging") geoducks by divers every day over a period of a week or two, until no new siphon shows are observed. The total number of flags after the last tagging dive (no new geoducks observed) provides a good estimate of the true population within the show plot. Once the total underlying population of geoducks within the show plot is known, the flags are extracted. A daily show factor can be determined by counting geoduck shows within the show plot on a particular survey day and dividing by the total underlying population estimate (census from tagging). This daily show factor can then be applied to diver observed transect counts to correct for the proportion of geoducks that may not be visible to divers on that day. For the Hood Canal surveys in 2005, a show plot near the community of Breidablick was used to correct the number of geoducks observed on tract transects. For surveys in previous years if no show plot was available, a standard show factor of 0.75 was applied to correct the geoduck counts (described further in section 5.1).

3.5 Analysis of survey data

The Hood Canal subtidal scuba surveys in this study estimate the mean (average) geoduck density for three pre-established unfished geoduck tracts using standard survey methods. A single factor-single variable analysis of variance (ANOVA) was used to detect differences in the means (Zar, 1999). The assumptions of this analysis are normal distribution and equality of variance of sampled populations. Mean densities were compared between survey years and also between tracts to determine differences. If differences between means were noted in the ANOVA, a Tukey test (1953) was performed to determine which mean densities were similar and which were different. Additional analysis and testing will be performed and summarized in the Phase 2 study report due to the legislature by January 1, 2007.

4.0 SURVEY RESULTS

4.1 Bridge geoduck tract (#20650)

The Bridge geoduck tract in Northern Hood Canal (Figure 4) covers a subtidal area of about 67 acres between the –18 feet (MLLW) and –70 foot (MLLW) water depth contours. This is different than the commercial geoduck area estimate (43 acres) for the Bridge tract, where the nearshore boundary line is established along the –31 foot (MLLW) water depth contour, to protect a nearshore eelgrass bed, thus making the harvestable portion of the tract smaller.

The Bridge tract was surveyed with 15 transects on May 14, 1986 and the site-specific show factor was 0.52 (52% of the geoduck siphons were showing). Average geoduck density, corrected with the show factor, was very high at 0.3865 geoducks/sq.ft. (Table 4). Substrate types noted were sand, peagravel, shell, and mud with sand being the predominant substrate type on 10 out of 15 transects and mud the predominant type on two transects, and the remaining transects had no single dominant substrate. Common and obvious plants (three species) and animals (18 species) associated with survey transects are listed in Tables 5 and 6.

The Bridge tract was surveyed with 25 transects from October 3 to October 9, 1995 and a standard show factor of 0.75 was used to adjust diver geoduck transect counts. A site-specific show factor was not undertaken during this survey and the 0.75 show factor applied at this time of year may bias the density estimate, if the geoducks were actually showing more poorly. Due to this bias, the actual density in 1995 is likely to be higher than the calculated 1995 estimate. Average geoduck density, corrected with the 0.75 show factor, was moderate at 0.2132 geoducks/sq.ft. (Table 4). Substrate types noted were cobble, gravel, mud, shell, sand, and peagravel, with mud being the predominant substrate type on 21 out of 25 transects, and gravel the predominant type on one transect. Common and obvious plants (four species) and animals (24 species) noted in 1995 are listed in Tables 5 and 6.

The Bridge tract was surveyed with 44 transects (Figure 6) from September 19 to September 22, 2005 and site-specific show factors of 0.628 and 0.503 (Table 7) were used to adjust diver observed geoduck transect counts. Average geoduck density was low at 0.0634 geoducks/sq.ft. (Table 4). Substrate types noted were sand, peagravel, gravel, shell, cobble and mud. Sand and mud were equally dominant substrate types, with each being predominant on 17 out of 44 transects. Gravel was the predominant type on three transects and cobble on one transect. Common and obvious plants (five species) and animals (46 species) associated with survey transects are listed in Tables 5 and 6.

Table 4. ANOVA calculations for the Bridge geoduck tract.

Survey years =	1986	1995	2005	Totals
n =	15	25	44	84
df =	14	24	43	
error df =				81
sum =	5.7970	5.3304	2.7892	13.9166
mean =	0.3865	0.2132	0.0634	
Sum squared/n =	2.2404	1.1365	0.1768	3.5537
Sum of sample squares =				5.7354
C =				2.3056
Total SS =				3.4297
Group SS =				1.2481
Error SS =				2.1817

SUMMARY OF ANALYSIS OF VARIANCE - BRIDGE TRACT

Source of Variation	SS	DF	MS
Total SS =	3.4297	83	
Group SS =	1.2481	2	0.6240
Error SS =	2.1817	81	0.0269

Testing null hypothesis

F-calc = 23.17

F-critical value* = 3.11

*(alpha = 0.05, one-tailed, sample df = 2, error df = 81)

Null hypothesis: There is no difference in geoduck density on this tract between survey years.

Alternate hypothesis: Mean geoduck densities on this tract are not equal between survey years, at

Conclusion: Reject null hypothesis.

TUKEY TEST - BRIDGE TRACT

Year	2005	1995	1986
Rank =	1	2	3
Ranked means =	0.0634	0.2132	0.3865
n =	44	25	15

Comparisons	Difference	SE	q-calc.	q-critical*	Conclusion
3 vs. 1	0.3231	0.0504	6.4140	3.399	Reject null hypothesis.
3 vs. 2	0.1733	0.0504	3.4395	3.399	Accept null hypothesis.
2 vs. 1	0.1498	0.0350	4.2798	3.399	Reject null hypothesis.

*(alpha = 0.05, Error df = 81, Means tested = 3)

Null hypothesis: There is no difference in geoduck density between the two means compared.

Alternate hypothesis: Mean geoduck densities on this tract are not equal between the two means

Overall conclusion: Ranked means 2 and 3 are similar and ranked mean 1 is not similar to ranked means 2 and 3. The mean geoduck density in 2005 is different than the mean densities in 1986 and 1995.

Table 5. Marine plant species observed during Bridge geoduck tract surveys.

		Year of Survey		
		1986	1995	2005
Common name	Taxonomer			
Desmerestia kelp	*Desmarestia* sp.		x	x
Laminaria kelp	*Laminaria* sp.	x	x	x
Sea Lettuce	*Ulva* sp.	x	x	x
Small red algae	Unspecified	x	x	x
Large red algae	Unspecified			x
Note: An “x” indicates presence of marine plant.				

Table 6. Marine animal species observed during Bridge geoduck tract surveys.

		Year of Survey		
		1986	1995	2005
Common name	Taxonomer			
Burrowing anemone	*Pachycerianthus fimbriatus*	x	x	x
Plumed anemone	*Metridium senile*	x	x	x
Striped anemone	*Urticina* sp.		x	x
Hardshell clams	*Veneridae* sp.	x	x	x
Heart cockle	*Clinocardium nuttalli*		x	x
Horse clam	*Tresus* sp.	x	x	x
False geoduck	*Panomya* sp.	x	x	
Horse mussel	*Modiolus rectus*		x	x
Jingleshell oyster	*Pododesmus macrochisma*			x
Moon snail egg case	*Polinices lewisii*	x	x	
Truncated Mya	*Mya truncata*		x	x
Dungeness crab	*Cancer magister*		x	x
Graceful crab	*Cancer gracilis*	x	x	x
Hermit crab	Unspecified hermit crab			x
Red Rock crab	*Cancer productus*	x	x	x
Sea cucumber	*Parastichopus californicus*	x	x	x
Bay pipefish	*Syngnathus leptorhynchus*			x
C-O sole	*Pleuronichthys coenosus*			x
English sole	*Parophrys vetulus*			x
Flatfish	Unspecified flatfish	x	x	x
Greenling	*Hexagrammos* sp.		x	x
Perch	Unspecified Embiotocidea			x
Poacher	Unspecified Agonidea			x
Ratfish	*Hydrolagus colliei*			x
Rock sole	*Lepidopsetta bilineata*			x
Sanddab	*Citharichthys* sp.			x
Sculpin	Unspecified cottid	x	x	x
Skate	Unspecified Raja sp.			x

Skate egg case	Unspecified *Raja* sp.		x	
Starry flounder	*Platichthys stellatus*			x
Bryozoan colony	Unspecified Bryozoan			x
Sand dollar	*Dendraster excentricus*			x
Sea pen	*Ptilosarcus gurneyi*		x	x
Sea whip	*Stylatula elongata*	x	x	x
Sponge	Unspecified Porifera			x
Armina nudibranch	*Armina californica*			x
Dirona nudibranch	*Dirona albolineata*			x
Hermissenda nudibranch	*Hermissenda crassicornis*			x
Rosy Tritonia nudibranch	*Tritonia diomedea*			x
Blood star	*Henricia leviuscula*	x		x
Sand star	*Luidia foliolata*			x
Short-spined star	*Pisaster brevispinus*	x	x	x
Sun star	*Solaster* sp.	x		x
Sunflower star	*Pycnopodia helianthoides*	x	x	x
Leather star	*Dermasterias imbricata*		x	
Vermillion star	*Mediaster aequalis*		x	
Ghost shrimp	Unspecified ghost shrimp	x		x
Shrimp	Unspecified shrimp			x
Roots	Chaetopterid polychaete tubes	x		x
Sabellid tube worm	*Sabellid* sp.			x
Terebellid tube worm	*Terebellid* sp.			x
Note: An “x” indicates presence of marine animal.				

The trend of average geoduck density at the Bridge is a decline between survey years (Figure 7). At a 95% confidence level, the mean density of geoducks is similar between survey years 1986 and 1995. The estimate of geoduck density in 2005 is statistically different and lower than the earlier survey estimates of geoduck density (Table 4). Qualitative observations of substrate types also appear to be different from survey year to survey year. Sand was the dominant substrate type in May of 1986, mud the dominant substrate type in October of 1995, and sand and mud held equivalent dominance of substrate types in September of 2005. The diversity of marine plant groups appears to increase from survey year to survey year, from qualitative observations. Likewise the diversity of animals tends to increase over time; though observations of false geoducks, moon snail egg cases, skate egg cases, leather stars, and vermillion stars made in 1986 and 1995 were not made in 2005.

Figure 6. Bridge Geoduck Tract # 20650, 2005 Survey Transect Locations

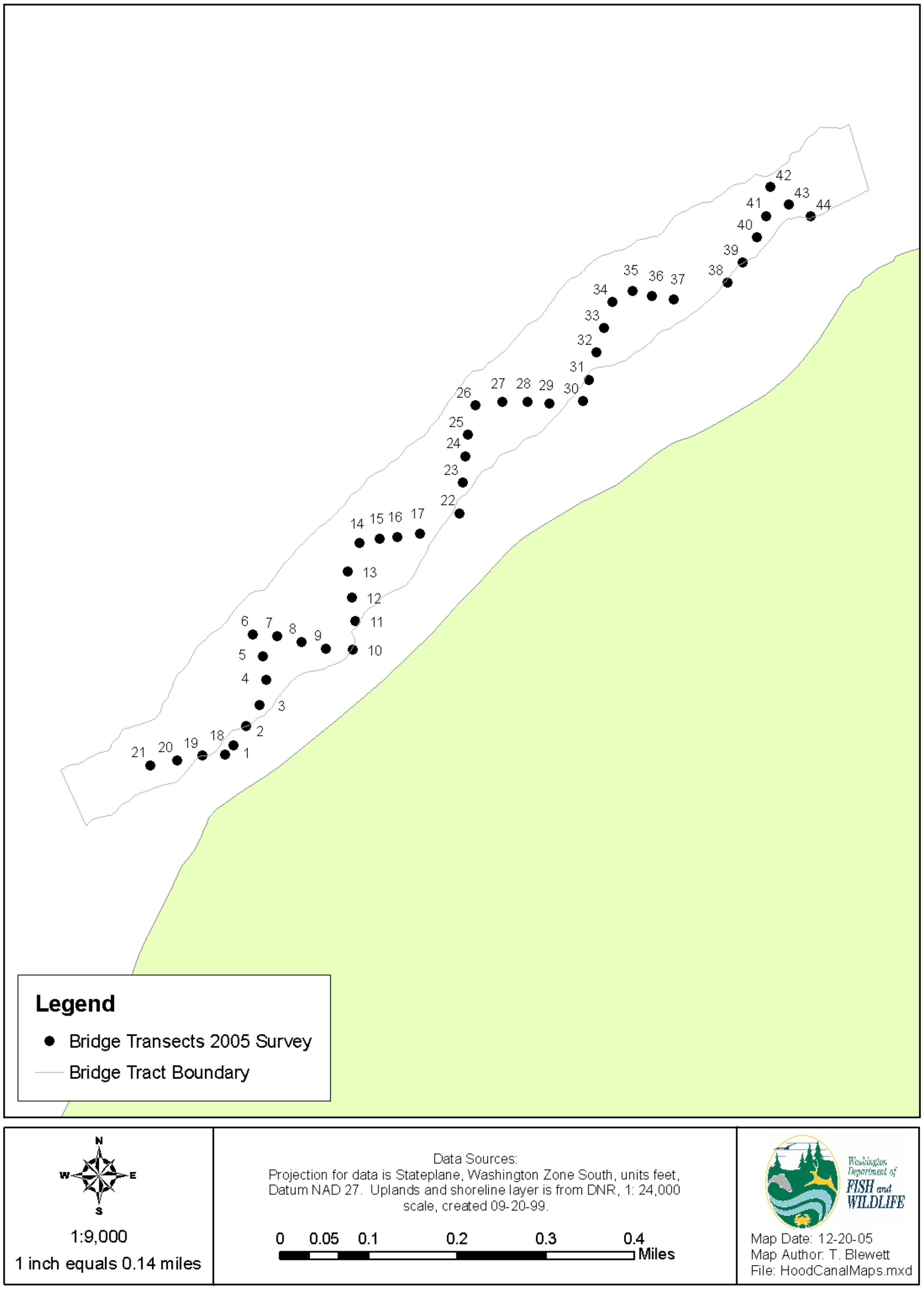
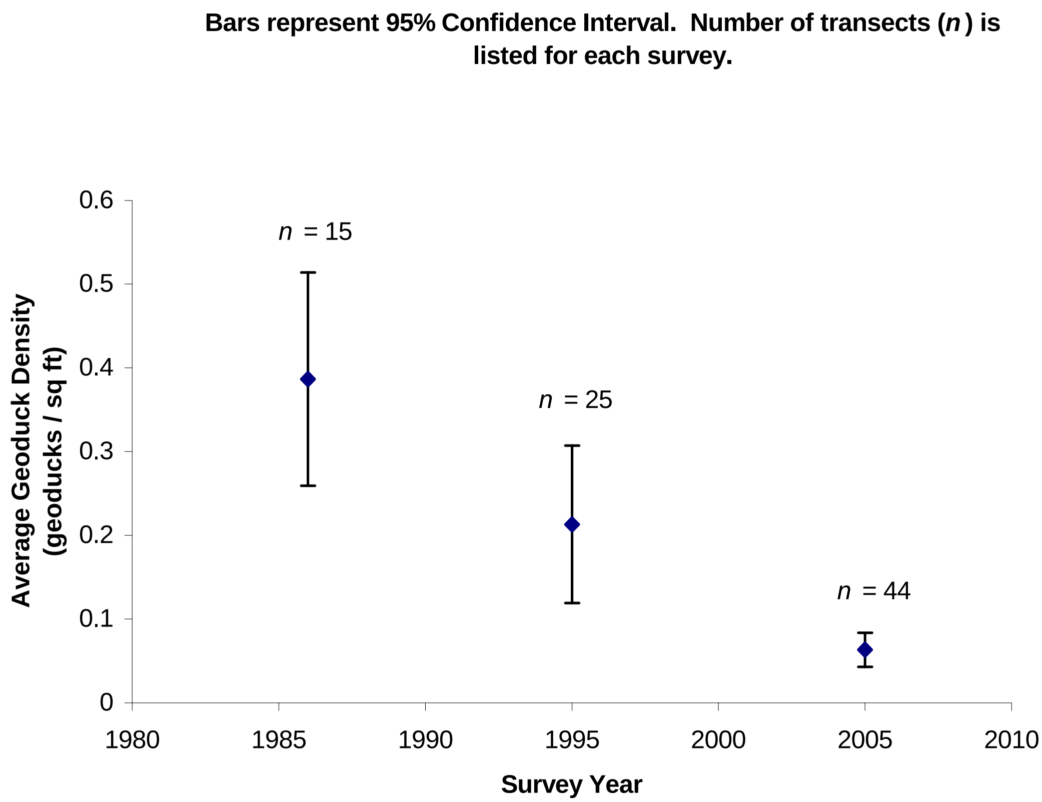


Figure 7. Average Geoduck Densities for Bridge Tract Surveys in 1986, 1995, and 2005



4.2 Dosewallips tract (#22250)

The Dosewallips geoduck tract in Central Hood Canal (Figure 4) covers a subtidal area, along the Dosewallips River delta, of about 20 acres between the –18 feet and –70 foot (MLLW) water depth contours. This is updated from a previous estimate (15 acres) for the Dosewallips tract, which used a rough hand-drawn image to estimate tract area.

The Dosewallips tract was surveyed with seven transects on October 23 and October 30, 1974 and the siphon show factors used were 0.29 and 0.44 (29% and 44% of the geoduck siphons were showing on respective survey dates). Average geoduck density, corrected with the show factors, was low at 0.0595 geoducks/sq.ft. (Table 8). Substrate types noted were silty sand (mud/sand mix), sand, peagravel, mud, and cobble. No dominant substrate type was noted except that soft sand substrates tended to be in shallow water depths and peagravel at deeper water depths. Common and obvious plants (one species) and animals (four species) associated with survey transects are listed in Tables 9 and 10.

The Dosewallips tract was surveyed with 20 transects on April 30, 1998 and a standard show factor of 0.75 was used to adjust diver geoduck transect counts. A site-specific show factor was not undertaken during this survey and the 0.75 show factor applied may bias the density estimate. Average geoduck density, corrected with the show factor, was low at 0.0576 geoducks/sq.ft. (Table 8). The actual density in 1995 may be higher than the 1995 estimate. Substrate types noted were mud, sand, gravel, and cobble with sand being the predominant substrate type on eight out of 20 transects. Common and obvious plants (four species) and animals (15 species) noted in 1998 are listed in Tables 9 and 10.

The Dosewallips tract was surveyed with 22 transects (Figure 8) from October 3 to October 4, 2005 and show factors (from the Breidablick show plot) of 0.474 and 0.559 (Table 7) were used to adjust diver geoduck transect counts. Average geoduck density was low at 0.0105 geoducks/sq.ft. (Table 8). Substrate types noted were mud, sand, gravel, shell, and cobble. Sand was the predominant substrate type on nine out of 22 transects. Cobble was the predominant substrate type on six transects and gravel was the predominant substrate type on two transects. Common and obvious plants (five species) and animals (34 species) associated with survey transects are listed in Tables 9 and 10.

The trend of average geoduck density at the Dosewallips is steady-state between survey years 1974 and 1995 (Figure 9). The mean densities (0.0595 and 0.0576 geoducks/sq.ft., respectively) are nearly identical between these two years. The comparison is biased, however, because all transects in 1974 were started shallow of the –18 ft (MLLW) water depth contour and only reach a maximum depth of –40 ft (MLLW). The mean tract density declines between the 1998 and 2005 surveys, from 0.0576 to 0.0105 geoducks/sq.ft. The 1998 and 2005 surveys of the Dosewallips are comparable in survey method and intensity. At a 95% confidence level the mean density of geoducks is similar between all survey years: 1974, 1998 and 2005 (Table 8). With the data available and analysis used, changes in density on this tract are inconclusive.

Qualitative observations of substrate types also appear to be similar from survey year to survey year at the Dosewallips tract. Comparing just 1998 and 2005, which had similar survey depths, sand was the dominant substrate type. However, cobble was not noted as a dominant substrate type in 1998 but was the second most predominant type in 2005. This could be attributed to seasonal differences at this location, a sign of a higher energy environment in recent years, or an artifact of random sample design. The diversity of marine plant groups appears to increase from survey year to survey year, from qualitative observations. Again, the 1974 survey used different methods for data gathering (diver recall onboard the dive vessel) than the 1998 and 2005 survey (standard *in situ* data recording on a dive slate). The increase of marine plant diversity may be due to improvements to survey method and diver experience, rather than ecological change. Likewise the diversity of animals observed tends to increase over time; though observations of pink scallops and sea cucumbers made in 1998 were not made in 2005. This could be attributed to seasonal differences (April 1998 survey vs. October 2005 survey).

Table 7. Daily geoduck siphon show factors at Breideblick Show Plot in Northern Hood Canal used to correct geoduck counts in the 2005 surveys of Bridge, Dosewallips, and Tahuya geoduck tracts. Show plot is 450 sq. ft. in size, total geoduck population = 290.

Date	Show Factor	Source
09/20/2005	0.628	Show plot visited today. Number of geoducks "showing" in plot = 182.
09/21/2005	0.628	Show plot visited today. Number of geoducks "showing" in plot = 182.
09/22/2005	0.503	Show plot visited today. Number of geoducks "showing" in plot = 146.
09/26/2005	0.390	Show plot visited today. Number of geoducks "showing" in plot = 113.
10/04/2005	0.559	Show plot visited today. Number of geoducks "showing" in plot = 162.
10/17/2005	0.545	Show plot visited today. Number of geoducks "showing" in plot = 158.
09/19/2005	0.628	Used the show factor from closest date (09/20/05).
10/03/2005	0.474	Used the average of the two show factors closest in date with this date: one before (09/26) and one after (10/04).
All dates for the Tahuya Survey	0.552	Used the average of the two show factors closest in date with this survey: one before (10/04) and one after (10/17).

Table 8. ANOVA calculations for the Dosewallips geoduck tract.

Survey years =	1974	1998	2005	Totals
n =	7	20	22	49
df =	6	19	21	
error df =				46
sum =	0.4163	1.1511	0.2320	1.7994
mean =	0.0595	0.0576	0.0105	
Sum squared/n =	0.0248	0.0663	0.0024	0.0935
Sum of sample squares =				0.2622
C =				0.0661
Total SS =				0.1961
Group SS =				0.0274
Error SS =				0.1687

SUMMARY OF ANALYSIS OF VARIANCE - DOSEWALLIPS TRACT

Source of Variation	SS	DF	MS
Total SS =	0.1961	48	
Group SS =	0.0274	2	0.0137
Error SS =	0.1687	46	0.0037

Testing null hypothesis

F-calc = 3.73

F-critical value* = 3.20

*(alpha = 0.05, one-tailed, sample df = 2, error df = 46)

Null hypothesis: There is no difference in geoduck density on this tract between survey years.
Alternate hypothesis: The mean geoduck densities on this tract are not equal between survey years, at alpha=0.05.

Conclusion: Reject null hypothesis.

TUKEY TEST - DOSEWALLIPS TRACT

Year	2005	1998	1974
Rank=	1	2	3
Ranked means=	0.0105	0.0576	0.0595
n=	22	20	7

Comparisons	Difference	SE	q -calc	q-critical*	Conclusion
3 vs. 1	0.0489	0.0186	2.6320	3.442	Accept null hypothesis.
3 vs. 2	0.0019	0.0188	0.1018	3.442	Do not test.
2 vs. 1	0.0470	0.0132	3.5521	3.442	Do not test.

*(alpha = 0.05, Error df = 46, Means tested = 3)

Null hypothesis: There is no difference in geoduck density between the two means compared.
Alternate hypothesis: The mean geoduck densities on this tract are not equal between the two means compared, at alpha=0.05.

Overall conclusion: Since there is no difference between ranked means 3 and 1, the conclusion is there is no difference between any of these means.

Table 9. Marine plant species observed during Dosewallips geoduck tract surveys.

		Year of Survey		
		1974	1998	2005
Common name	Taxonomer			
Eelgrass	*Zostrea marina*	x		
Diatoms	Unspecified		x	x
Turkish towel	*Gigartina papillata*		x	
Laminaria kelp	*Laminaria* sp.		x	x
Small red algae	Unspecified		x	x
Large red algae	Unspecified			x
Small brown algae	Unspecified			x
Note: An "x" indicates presence of marine plant.				

Table 10. Marine animal species observed during Dosewallips geoduck tract surveys.

		Year of Survey		
		1974	1998	2005
Common name	Taxonomer			
Striped anemone	*Urticina sp.*			x
Hardshell clams	*Veneridae sp.*	x	x	x
Heart cockle	*Clinocardium nuttalli*			x
Horse clam	*Tresus spp.*	x	x	x
Pink scallop	*Chlamys rubida*		x	
Jingleshell oyster	*Pododesmus macrochisma*			x
Dungeness crab	*Cancer magister*	x	x	x
Graceful crab	*Cancer gracilis*		x	x
Hermit crab	Unspecified hermit crab			x
Pinch bug	*Munida quadrispina*		x	x
Red Rock crab	*Cancer productus*		x	x
Sea cucumber	*Parastichopus californianus*		x	
C-O sole	*Pleuronichthys coenosus*			x
English sole	*Parophrys vetulus*			x
Fish	Unspecified fish			x
Flatfish	Unspecified flatfish		x	x
Sanddab	*Citharichthys sp.*			x
Sculpin	Unspecified cottid			x
Starry flounder	*Platichthys stellatus*			x
Tubesnout	*Aulorhynchus flavidus*			x
Moon snail	*Polinices lewisii*		x	
Moon snail egg case	*Polinices lewisii* egg case		x	x
Arthropod	Unspecified Arthropod			x
Bryozoan colony	Unspecified Bryozoan			x
Sea pen	*Ptilosarcus gurneyi*			x
Sessile tunicate	Unspecified Tunicate			x
Sponge	Unspecified Porifera			x

Armina nudibranch	*Armina californica*			x
Dendronotus nudibranch	*Dendronotus sp.*			x
Dirona nudibranch	*Dirona sp.albolineata*			x
False ochre star	*Evasterias troschelli*		x	x
Short-spined star	*Pisaster brevispinus*		x	x
Sunflower star	*Pycnopodia helianthoides*		x	x
Sea star	Unspecified sea star	x		
Shrimp	Unspecified shrimp			x
Roots	Chaetopterid polychaete		x	x
Terebellid tube worm	*Terebellid sp.*			x
Worm	Unspecified Annelid worm			x
Note: An “x” indicates presence of the marine animal.				

Figure 8. Dosewallips Geoduck Tract # 22250, 2005 Survey Transect Locations

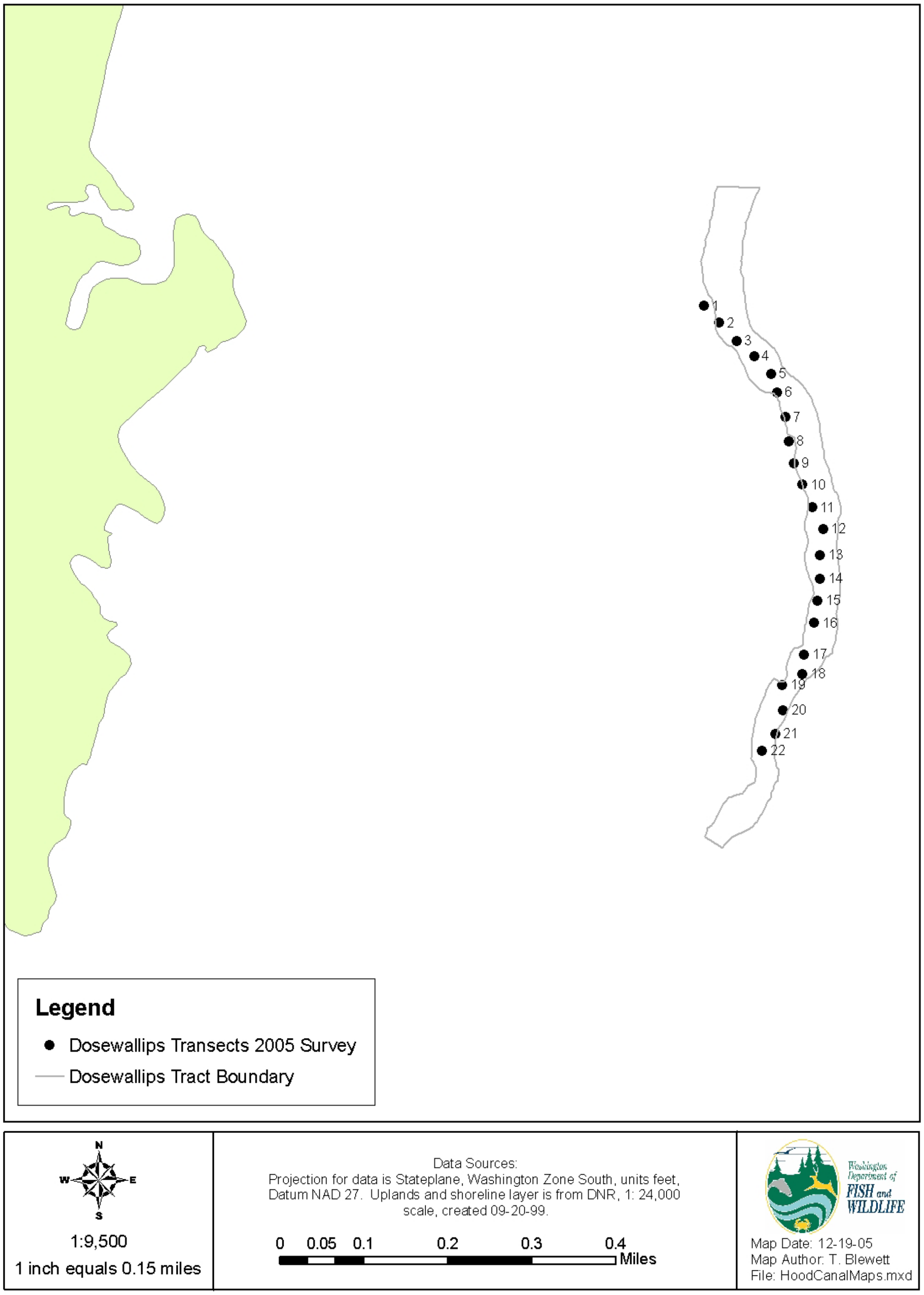
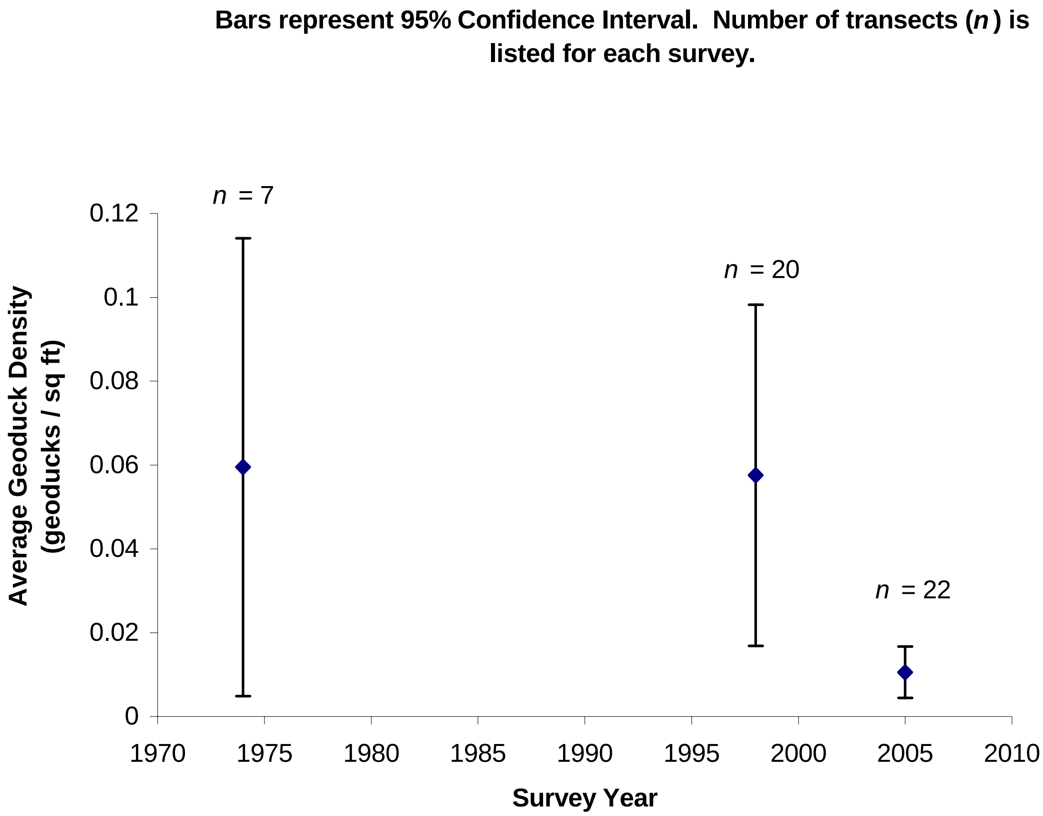


Figure 9. Average Geoduck Density Estimates for the Dosewallips Tract Surveys in 1974, 1998, and 2005



4.3 Tahuya tract (#23550)

The Tahuya geoduck tract in Southern Hood Canal (Figure 4) covers a subtidal area along the Tahuya River delta of about 241 acres between the –18 feet and –70 foot (MLLW) water depth contours. An initial estimate of tract area from a hand-drawn figure was 82 acres.

The Tahuya tract was surveyed with 9 transects on June 9, 1978. It was not clear what show factor was used for this survey, so for purposes of this study the unadjusted counts are used for the 1978 density estimate. This will tend to underestimate the true population density for the 1978 survey. The estimate of average geoduck density, uncorrected with a show factor, was low at 0.0293 geoducks/sq.ft. (Table 11). Substrate types noted were sand and mud. No dominant substrate type was noted, except that sand substrates tended to be in shallow water depths and mud at deeper water depths. Common and obvious plants (none observed or noted) and animals (six species) associated with survey transects are listed in Tables 12 and 13.

The Tahuya tract was surveyed with 52 transects from April 16 to April 18, 1996 and a standard show factor of 0.75 was used to adjust diver geoduck transect counts. A site-specific show factor was not undertaken during this survey and the 0.75 show factor applied may bias the density estimate. Average geoduck density, corrected with the show factor, was low at 0.0021 geoducks/sq.ft. (Table 11). Substrate types noted were mud, sand, gravel, and cobble with sand being the predominant substrate type on 35 out of 52 transects. Mud was the predominant substrate type on 9 out of 52 transects. Common and obvious plants (one type) and animals (22 species) observed are listed in Tables 12 and 13. It should be noted that no tunicates were observed and recorded during the 1978 and 1996 surveys.

The Tahuya tract was surveyed with 74 transects (Figure 10) from October 5 to October 13, 2005 and show factor (an average from the Breidablick show plot) of 0.552 (Table 7) was used to adjust diver geoduck transect counts. Average geoduck density was low at 0.0040 geoducks/sq.ft. (Table 11). Substrate types noted were mud, sand, peagravel, gravel, and cobble. Sand was the predominant substrate type on 54 out of 74 transects. Mud was the predominant substrate type on 12 transects and peagravel was the predominant substrate type on 3 transects. Common and obvious plants (7 species) and animals (48 species) associated with survey transects are listed in Tables 12 and 13. A non-native sessile tunicate, *Ciona savignyi*, was observed on 54 of the 74 transects on the Tahuya tract in 2005 (Figure 11). Dr. Gretchen Lambert, an expert in the study of tunicates, confirmed the identification of this invasive species. This species is light sensitive (Olah, 2001) and was not observed on the most shallow transects. The upper limit to its vertical distribution at this site was -24 ft (MLLW) of water depth.

Figure 10. Tahuya Geoduck Tract # 23550, 2005 Survey Transect Locations

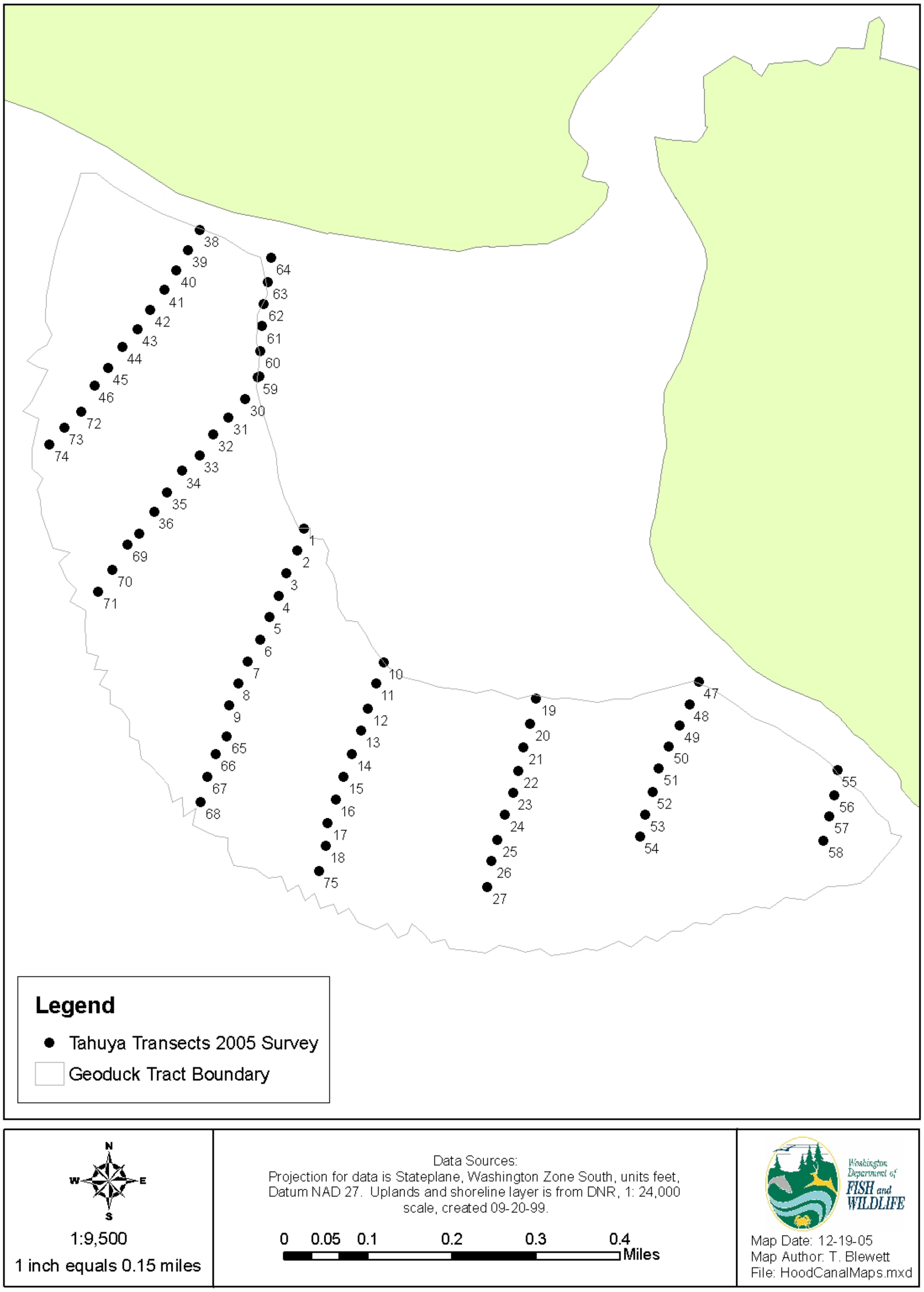


Figure 11. Tahuya Geoduck Tract # 23550, Transects with Invasive Tunicate

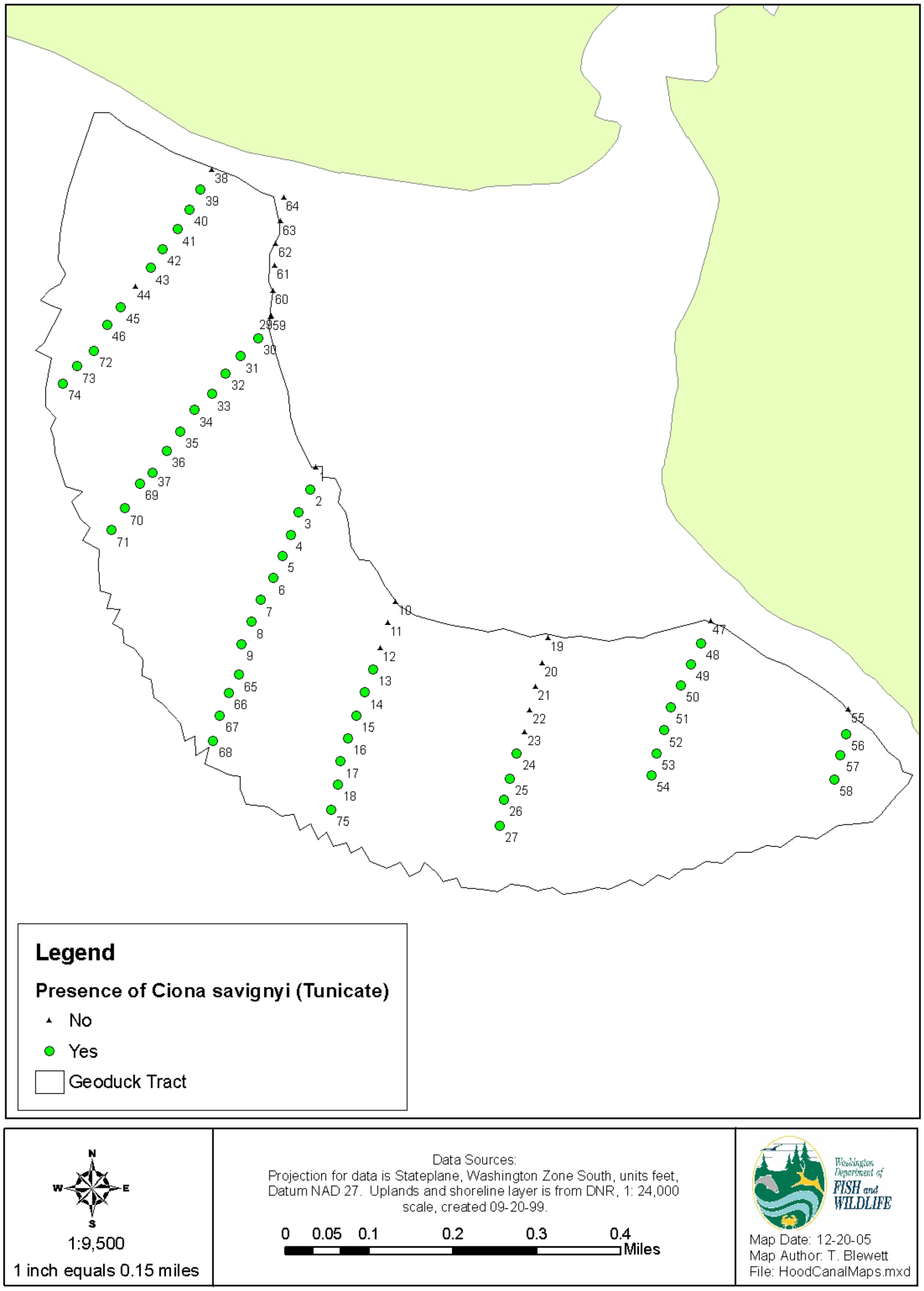


Table 11. ANOVA calculations for the Tahuya geoduck tract.

Survey years =	2005	1996	1978	Totals
n =	74	52	9	135
df =	73	51	8	
error df =				132
sum =	0.2959	0.1081	0.2633	0.6674
mean =	0.0040	0.0021	0.0293	
Sum squared/n =	0.0012	0.0002	0.0077	0.0091
Sum of sample squares =				0.0145
C =				0.0033
Total SS =				0.0112
Group SS =				0.0058
Error SS =				0.0053

SUMMARY OF ANALYSIS OF VARIANCE - TAHUYA TRACT

Source of Variation	SS	DF	MS
Total SS =	0.0112	134	
Group SS =	0.0058	2	0.0029
Error SS =	0.0053	132	0.0000

Testing null hypothesis

F-calc = 71.88

F-critical value* = 3.07

*(alpha = 0.05, one-tailed, sample df = 2, error df = 132)

Null hypothesis: There is no difference in geoduck density on this tract between survey years.
Alternate hypothesis: The mean geoduck densities on this tract are not equal between survey years, at alpha=0.05.

Conclusion: Reject null hypothesis.

TUKEY TEST - TAHUYA TRACT

Year	1996	2005	1978
Rank =	1	2	3
Ranked means =	0.0021	0.0040	0.0293
n =	52	74	9

Comparisons	Difference	SE	q -calc	q-critical*	Conclusion
3 vs. 1	0.0272	0.0016	16.7450	3.356	Reject null hypothesis.
3 vs. 2	0.0253	0.0016	15.9149	3.356	Reject null hypothesis.
2 vs. 1	0.0019	0.0008	2.3598	3.356	Accept null hypothesis.

*(alpha = 0.05, Error df = 132, Means tested = 3)

Null hypothesis: There is no difference in geoduck density between the two means compared.
Alternate hypothesis: The mean geoduck densities on this tract are not equal between the two means compared, at alpha=0.05.

Overall conclusion: The mean density in 1978 is not similar to the mean densities for 1996 and 2005. The mean density for 1996 and 2005 are similar to each other.

Table 12. Marine plant species observed during Tahuya geoduck tract surveys.

		Year of Survey		
		1978	1996	2005
Common name	Taxonomer			
Eelgrass	*Zostrea marina*			x
Diatoms	Unspecified		x	x
Turkish towel	*Gigartina papillata*			x
Laminaria kelp	*Laminaria* sp.			x
Iridea	*Iridea cordata*			x
Small red algae	Unspecified			x
Large red algae	Unspecified			x
Note: An "x" indicates presence of the marine plant.				

Table 13. Marine animal species observed during Tahuya geoduck tract surveys.

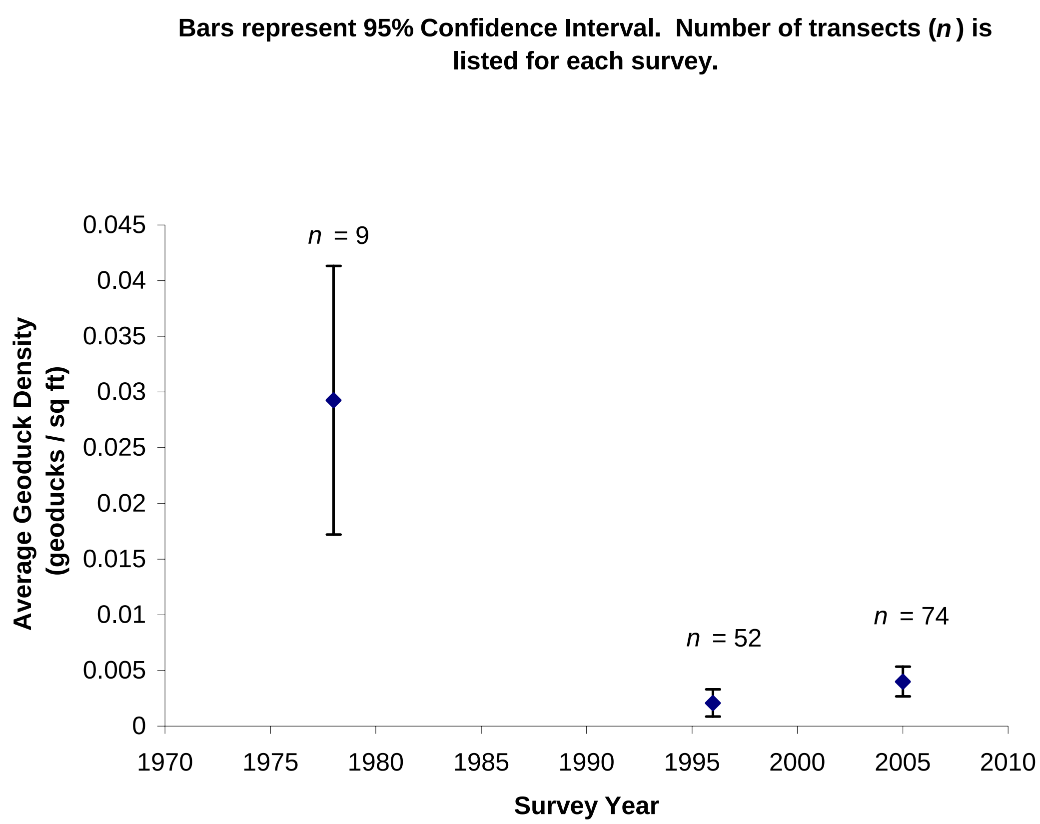
		Year of Survey		
		1978	1996	2005
Common name	Taxonomer			
Burrowing anemone	*Pachycerianthus fimbriatus*	x	x	x
Plumed anemone	*Metridium senile*		x	x
False geoduck	*Panomya* sp.			x
Hardshell clams	*Veneridae sp.*		x	x
Heart cockle	*Clinocardium nuttalli*		x	x
Horse clam	*Tresus spp.*		x	x
Horse mussel	*Modiolus rectus*		x	x
Mollusc	Unspecified bivalve mollusc			x
Truncated Mya	*Mya truncata*			x
Hydroids	Unspecified Hydroid			x
Decorator crab	*Pugettia* sp.			x
Dungeness crab	*Cancer magister*	x	x	x
Graceful crab	*Cancer gracilis*			x
Hermit crab	Unspecified hermit crab			x
Red Rock crab	*Cancer productus*		x	x
White cucumber	*Eupentacta quinquesemita*		x	
Cabezon	*Scorpaenichthys marmoratus*	x		
Bay pipefish	*Syngnathus leptorhynchus*			x
English sole	*Parophrys vetulus*			x
Flatfish	Unspecified flatfish		x	x
Ratfish	*Hydrolagus colliei*	x		
Sand sole	*Psettichthys melonostictus*			x
Sanddab	*Citharichthys* sp.			x
Sculpin	Unspecified cottid			x
Starry flounder	*Platichthys stellatus*			x
Skate egg case	*Raja* sp. egg case		x	x

Moon Snail	*Polinices lewisii*		x	x
Nudibranch	Unspecified nudibranch		x	x
Arthropod	Unspecified Arthropod			x
Sea pen	*Ptilosarcus gurneyi*	x		x
Sea whip	*Stylatula elongata*	x	x	x
Sessile tunicate	Unspecified Tunicate			x
Sponge	Unspecified Porifera			x
Armina nudibranch	*Armina californica*			x
Dendronotus nudibranch	*Dendronotus sp.*			x
Dirona nudibranch	*Dirona albolineata*			x
Hermissenda nudibranch	*Hermissenda crassicornis*			x
Rosy Tritonia nudibranch	*Tritonia diomedea*			x
Fish-eating star	*Stylasterias forreri*			x
Leather star	*Dermasterias imbricata*			x
Rainbow star	*Orthasterias koehleri*			x
False ochre star	*Evasterias troschelli*		x	
Sand star	*Luidia foliolata*		x	x
Short-spined star	*Pisaster brevispinus*		x	x
Sunflower star	*Pycnopodia helianthoides*		x	x
Sun star	*Solaster* sp.		x	
Vermillion star	*Mediaster aequalis*			x
Ghost shrimp	Unspecified ghost shrimp		x	x
Shrimp	Unspecified shrimp			x
Roots	Chaetopterid polychaete tubes		x	x
Sabellid tube worm	*Sabellid* sp.		x	x
Terebellid tube worm	*Terebellid* sp.			x
Worm	Unspecified Annelid worm			x
Note: An “x” indicates presence of the marine animal.				

The trend of average geoduck density at the Tahuya tract is a decline between survey years 1978 and 1996 (from 0.0293 to 0.0021 geoducks/sq.ft.) by an order of magnitude. This decline in mean density estimates between 1978 and 1996 may be underestimated, since no show factor was used to correct the 1978 transect counts. The average geoduck density estimates are near steady-state between 1996 and 2005 (Figure 12). The 1996 and 2005 surveys of the Tahuya tract are comparable in survey method and intensity, except for use of a standard 0.75 show factor, which may bias the density estimate in 1996. The show factor used in 2005 to correct Tahuya tract transect counts is from a show plot which is located in the Northern Hood Canal sub-region, which is also a cause of bias in the 2005 density estimates. At a 95% confidence level, the mean density estimate of geoducks is similar between survey years 1996 and 2005 (Table 11). At a 95% confidence level, the mean density estimate of geoducks is different between survey year 1978 and both survey years 1996 and 2005 (Table 11).

Qualitative observations of substrate types appear to be similar from survey year to survey year at the Tahuya tract, indicating relatively stable energy conditions within the tract area. The diversity of marine plant groups appears to increase from survey year to survey year, from qualitative observations. Again, the 1978 survey used different methods for data gathering (diver recall onboard the dive vessel) than the 1996 and 2005 survey (standard *in situ* data recording on a dive slate). The increase of marine plant diversity may be due to improvements to survey method and diver experience, rather than ecological change. Likewise, the diversity of animals observed tends to increase over time; though observations of white cucumbers, cabezon, and false ochre stars made in 1978 and 1996 were not made in 2005.

Figure 12. Average Geoduck Density Estimates for the Tahuya Tract Surveys in 1978, 1996, and 2005



A notable difference in the composition of animals on this tract is the abundance of the invasive tunicate, *Ciona savignyi*. The 2005 observation on the Tahuya tract is the first confirmed report of this species occurring in southern Hood Canal. In a 2005 annual summary to WDFW, Dr. Gretchen Lambert reported the following observations related to *Ciona savignyi*:

> “I confirmed the identity of *Ciona savignyi* from geoduck tracts at the south end of Hood Canal, at the mouth of the Tahuya River, collected by Don Rothaus and Bob Sizemore of WDFW. While it is easy for me to distinguish *C. savignyi* from *C. intestinalis* by surface features, the definitive comparison involves a very tedious and difficult dissection of perfectly relaxed and preserved specimens, so Bob supplied me with living animals so that I could preserve them myself. There were no *Ciona* at this site in the 1990’s, but now there are thousands. Bob wrote: “We appreciate all of your work on these critters. In my 15 years of diving with WDFW, this was one of the more unusual and startling observations that we've made.”
>
> *Ciona savignyi* was very abundant at Des Moines Marina in 1998 (Cohen, A., Mills, C., Berry, H., Wonham, M., Bingham, B., Bookheim, B., Carlton, J., Chapman, J., Cordell, J., Harris, L., Klinger, T., Kohn, A., Lambert, C., Lambert, G., Li, K., Secord, D. and Toft, J. 1998. Report of the Puget Sound Expedition Sept. 8-16, 1998; A Rapid Assessment Survey of Non-indigenous Species in the Shallow Waters of Puget Sound. Wash. State Dept. Nat. Res., Olympia, WA. 37 pp.). It was absent from Edmonds Marina but had begun to appear by 1999 and is now very abundant at Edmonds and continues to be abundant at Des Moines. My husband and I survey a number of sites around Puget Sound periodically for invasive ascidians, and have found *C. savignyi* at the Tacoma Yacht Club also.”

After conferring with a WDFW marine fish biologist, Bob Pacunski, the invasion of this species in Southern Hood Canal appears to be a recent occurrence, within the last year or two, based on rock fish index site observations. Also the tunicate is distributed horizontally from the Tahuya River delta to subtidal lands along the southern shoreline of Hood Canal in the vicinity of the town of Union. The extent of the distribution of this tunicate beyond these observations, as well as the ecological impacts to Hood Canal marine communities, are unknown.

4.4 Comparison of 2005 density estimates between the three tracts

For the three tracts surveyed in Hood Canal in 2005, a comparison of mean density estimates were made (Table 14). In 2005 the average density estimates for the Bridge tract, Dosewallips tract, and Tahuya tract were 0.0634, 0.0105, and 0.0040 geoducks/sq.ft., respectively. At the 95% confidence level Dosewallips (Central Hood Canal) and Tahuya (South Hood Canal) have similar densities in 2005, and Bridge tract (North Hood Canal) is significantly different (higher average density) than the other two tracts.

Table 14. ANOVA Calculations for Geoduck Surveys in 2005.

Survey areas =	South HC	Central HC	North HC	Totals
n =	74	22	44	140
df =	73	21	43	
error df =				137
sum =	0.2959	0.2320	2.7892	3.3171
mean =	0.0040	0.0105	0.0634	
Sum squared/n =	0.0012	0.0024	0.1768	0.1804
Sum of sample squares =				0.3789
C =				0.0786
Total SS =				0.3003
Group SS =				0.1018
Error SS =				0.1985

SUMMARY OF ANALYSIS OF VARIANCE - THREE GEODUCK TRACTS IN 2005

Source of Variation	SS	DF	MS
Total SS =	0.3003	139	
Group SS =	0.1018	2	0.0509
Error SS =	0.1985	137	0.0014

Testing null hypothesis

F-calc = 35.15

F-critical value* = 3.07

*(alpha = 0.05, one-tailed, sample df = 2, error df = 137)

Null hypothesis: There is no difference in geoduck densities between surveyed areas; North, Central, South

Alternate hypothesis: The mean geoduck densities are not equal between surveyed areas, at alpha=0.05.

Conclusion: Reject null hypothesis.

TUKEY TEST - NORTH, CENTRAL, AND SOUTH TRACTS

Areas =	South HC	Central HC	North HC
Rank =	1	2	3
Ranked means =	0.0040	0.0105	0.0634
n =	74	22	44

Comparisons	Difference	SE	q-calc.	q-critical*	Conclusion
3 vs. 1	0.0594	0.0051	11.5981	3.356	Reject null hypothesis.
3 vs. 2	0.0528	0.0070	7.5182	3.356	Reject null hypothesis.
2 vs. 1	0.0065	0.0065	1.0016	3.356	Accept null hypothesis.

*(alpha = 0.05, Error df = 137, Means tested = 3)

Null hypothesis: There is no difference in geoduck density between the two means compared.

Alternate hypothesis: The mean geoduck densities compared are not equal.

Overall conclusion: Ranked means 1 and 2 are similar and ranked mean 3 is not similar to ranked means 1 and 2. The mean geoduck density on the North Hood Canal tract is different than the mean densities on the South and Central Hood Canal tracts.

5.0 SURVEY CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions for survey work and density estimates

The 2005 survey of the three tracts in separate sub-regions in Hood Canal was undertaken in the Fall, when geoduck siphon show is highly variable. Fortunately, there was a pre-existing show plot in close vicinity to the Bridge tract to make corrections to observed geoduck counts, to estimate the underlying population density. The Breidablick show plot is established in a current swept area and has conditions very similar to conditions found on the Bridge tract. Using this show plot for the Dosewallips tract and Tahuya tract in 2005 was necessary, because there was insufficient time to establish site-specific show plots at these two locations and complete the surveys in 2005 (a requirement of HB1896). This is an important source of bias when calculating density estimates for the Dosewallips and Tahuya tracts in 2005.

Year-to-year comparisons of geoduck density estimates on these three tracts have additional bias related to show factor, as well as other inherent problems. For the early surveys in the 1970’s the primary objective was to identify general areas that have geoducks and to evaluate these areas as to their commercial harvest potential. If an area “looked” promising, a more intensive pre-fishing survey was conducted. The low intensity of these initial surveys (low number of transects) can result in high variability and poor representation of tract density. This is further complicated by the poor quality of location information which was available during these early surveys, documentation of show plot location and data, experience of divers new to the fishery, and lack of standardized methods. The second surveys on these tracts used a standard show factor of 0.75 to adjust diver counts. The 0.75 show factor is a rough average of the highest show month (March) for all show data collected in Puget Sound. It was used in the 1990’s when budget constraints forced abandonment of site-specific show plots, and is intended to under-estimate geoduck density and result in a conservative estimate of density for fishery management. As actual siphon show factors tend to decline in Puget Sound from March to October, the 0.75 show factor used to adjust counts has the potential to underestimate true (underlying) geoduck density.

A quantified trend analysis could be done for year-to-year comparisons of density estimates, but given the biases and inherent problems noted above, the trends might be more related to differences in sampling methods than real changes in the geoduck populations. Until several data points using the same standardized methodology are collected, caution should be taken in making comparisons and analyzing trends. Further discussion of conclusions will be in terms of apparent relationships.

The apparent decline of geoduck density at the Bridge tract is dramatic and possibly more severe in recent years. Causal relationships for the decline in density are not known, however, the shift in substrate types from year-to-year may have an effect on geoduck density. On prior geoduck surveys in current swept locations, geoduck shells have been observed exposed above a shifting sand substrate in an upright orientation. Since adult geoducks have a reduced digging foot (compared to juvenile geoducks and other bivalve species) and cannot re-dig into the substrate, exposure above the substrate would make geoducks highly vulnerable to predation. Other causes for density decline may be undocumented harvest, poor recruitment, high predation, or changes in environmental conditions. Phase 2 of this study, which includes examination of the age of geoducks from shell samples, may provide insight into recruitment and year-class strength, growth, and natural mortality. A chemical analysis of geoduck shells should provide information to compare changes in the environment over time and correlate the conditions experienced by infaunal geoducks with information collected at water monitoring stations.

There is an apparent decline of geoduck density at the Dosewallips tract between the 1998 and 2005 surveys, though the overall results are inconclusive. This tract had no major shifts in the substrate types from year-to-year, though the tract is steep along the deep margin and it is conceivable that heavy rainfall events or large tidal exchanges could cause dynamic changes in the substrate from time to time. As noted above, changes in recruitment and causes of mortality cannot be determined from this type of tract survey.

There is an apparent decline of geoduck density at the Tahuya tract between surveys in 1978 and 1996. Even though this tract is along the Tahuya River delta, there were no major shifts in the substrate types observed from survey year to survey year. The tract geoduck density appears to be fairly stable in recent years. The establishment of the invasive tunicate, *Ciona savignyi*, may be an indicator of ecological change in this area. This tunicate is attached to hard surfaces (as small as pebbles) within the tract. Without quantitative information about other species occupying this niche, it may be difficult to compare the magnitude of ecological change that has already occurred. However, this tunicate is likely displacing native marine animals such as mussels, snails, and barnacles. Another sign of ecological change in Southern Hood Canal is the apparent decline of the white sea cucumber, *Eupentacta quinquesemita*. Other sea cucumber species (*Parastichopus* sp. and *Cucumaria* sp.) were observed by WDFW divers to be intolerant of low dissolved oxygen conditions during an October 15, 2002 dive at Sund Rock in Central Hood Canal. During this low dissolved oxygen event, WDFW divers observed sea cucumbers that were either dead or moribund, lying on exposed surfaces of rocky substrate.

If the geoduck density estimates from these tracts signal shifts in the ecology of Hood Canal, then one might surmise that the changes occurred first in Southern Hood Canal. The timing of the largest density decline at the Tahuya tract in Southern Hood Canal was between the first (1978) and second (1996) survey. Central and Northern Hood Canal may currently be undergoing ecological change. The largest density decline at the Dosewallips and Bridge tracts in Central and Northern Hood Canal was between the second (1995 and 1998) and third surveys (2005).

5.2 Recommendations for survey work

To control for bias associated with geoduck siphon show, show plots should be established for all survey sites used in future studies. Phase 2 of this work includes establishment of geoduck index stations in northern, central, and southern Hood Canal. The management objective of the index station is to monitor changes in geoduck abundance (recruitment and natural mortality) over time. The index stations are *de facto* show plots and can be used for surveys when the conditions are similar between the show plot and survey site, and the show plot is located in close proximity to the survey site.

To control for differences in sampling methods, the standard methodology will be used on tracts that are included in future density studies. As time allows, additional tracts from each sub-region should be included in the study to obtain a larger representative sample.

Since shifts in substrate and substrate composition may be important factors related to geoduck beds, the substrate types should be quantified with core samples and bathymetry mapping should be undertaken on study tracts.

To gain additional information about geoduck populations over time, we continue to recommend sampling geoduck shells for age analysis. Samples taken in 2005 (in close proximity to water monitoring stations) should be aged and analyzed to determine year-class strength, estimate growth, and estimate natural mortality of geoduck populations in Northern, Central, and Southern Hood Canal.

To detect environmental changes that geoduck populations may have experienced over the past several decades, we continue to recommend analysis of geoduck shells for trace elements and isotopes from samples taken in 2005.

The distribution and ecology of the non-native invasive tunicate, *Ciona savignyi*, in Southern Hood Canal is poorly understood. On the Tahuya geoduck tract it was a dominant epibenthic animal. A survey of the distribution of *Ciona savignyi* should be undertaken, beginning in Southern Hood Canal, to better understand vertical and horizontal distributions of this animal in Hood Canal and its potential impacts to the ecology of this system.

6.0 STATUS OF STUDY REPORTS DUE JANUARY 1, 2007

6.1 Geoduck index stations

Geoduck index stations are delineated subtidal areas (900 sq.ft. or larger) that are initially located in the mid-range of water depths for surveyed geoduck tracts. The current survey depths are –18 to –70 feet (corrected to MLLW) and the index stations will be located at about the -44 foot water depth (MLLW). The stations will have the same or similar dimensions of a survey transect (6 ft. x 150 ft.), to facilitate diver observations. The orientation of the index station will be parallel to the shoreline. There is currently one show plot established at Breidablick in Northern Hood Canal that can be used as a *de facto* index station. Flagging (non-intrusive tagging) geoducks for a period of several weeks, until a time when no more geoducks show, will provide an estimate of the true population of geoducks within the plot (see discussion of "show plot" in section 3.4). Periodically re-flagging (re-tagging) the same plot after several years will give an indication of changes in geoduck abundance at that site. Establishment of index stations is planned for the Central and Southern Hood Canal sub-regions in 2006.

6.2 Digging and aging of geoduck shells

The Washington Department of Natural Resources, Washington Department of Fish and Wildlife, University of Washington and a scientist at Makah Fisheries are working collaboratively to collect, age, and then sub-sample geoduck shells for chemical analysis. The objective to aging geoduck shells is to determine age frequency distributions for a geoduck population. A large sample will increase the likelihood of a particular year-class being represented in the sample. In geoduck clams, there may be more than 130 year classes represented as annuli in an old shell. In 2005, 505 shells were collected in the Lofall/Vinland area of Northern Hood Canal, 554 shells from the Hamma Hamma area of Central Hood canal, and 103 shells from the Tahuya tract in Southern Hood Canal (Figures 13, 14, 15, and 16). Additional geoduck samples may be taken from the Tahuya geoduck tract in the late Spring of 2006, when geoducks are "showing" better and can be dug more efficiently. Aging has begun on the Tahuya tract sample, and about 50 geoduck shells have been aged (as of December of 2005). It is anticipated that aging can be completed by mid-2006 and analysis of the data can begin thereafter.

6.3 Water samples at dig locations

Water samples were collected at 0.0 (MLLW) and -54 ft (MLLW) water depths for each dig area (Figure 13) to test for stable oxygen isotopes. Temperature and salinity measurements were taken at the same times and locations of the water samples. The GPS locations of the samples were also acquired. The water samples collected (60 total) will serve as a baseline ambient level for stable isotope analysis in the geoduck shells. This is necessary to create valid and dependable chronologies of the ambient environment (Weidman, *et al.*, 1994).

6.4 Chemical analysis of shells

The objective of this study is to determine changes in geoduck shell chemistry over time, correlate chemical composition to ambient water data, and to reconstruct environmental conditions experienced by geoducks over time including temperature, salinity, and dissolved oxygen. Recognition of annual cycles of oxygen and carbon isotopes may validate an aging technique that uses refractive light to discern annuli (in 6.2 above), as suggested by Romanek (1987). The analysis of elements and isotopes in geoduck shells will occur in late 2006, after the shells have been aged.

Figure 13. Geoduck Dig Sites for the Hood Canal Low Dissolved Oxygen Project

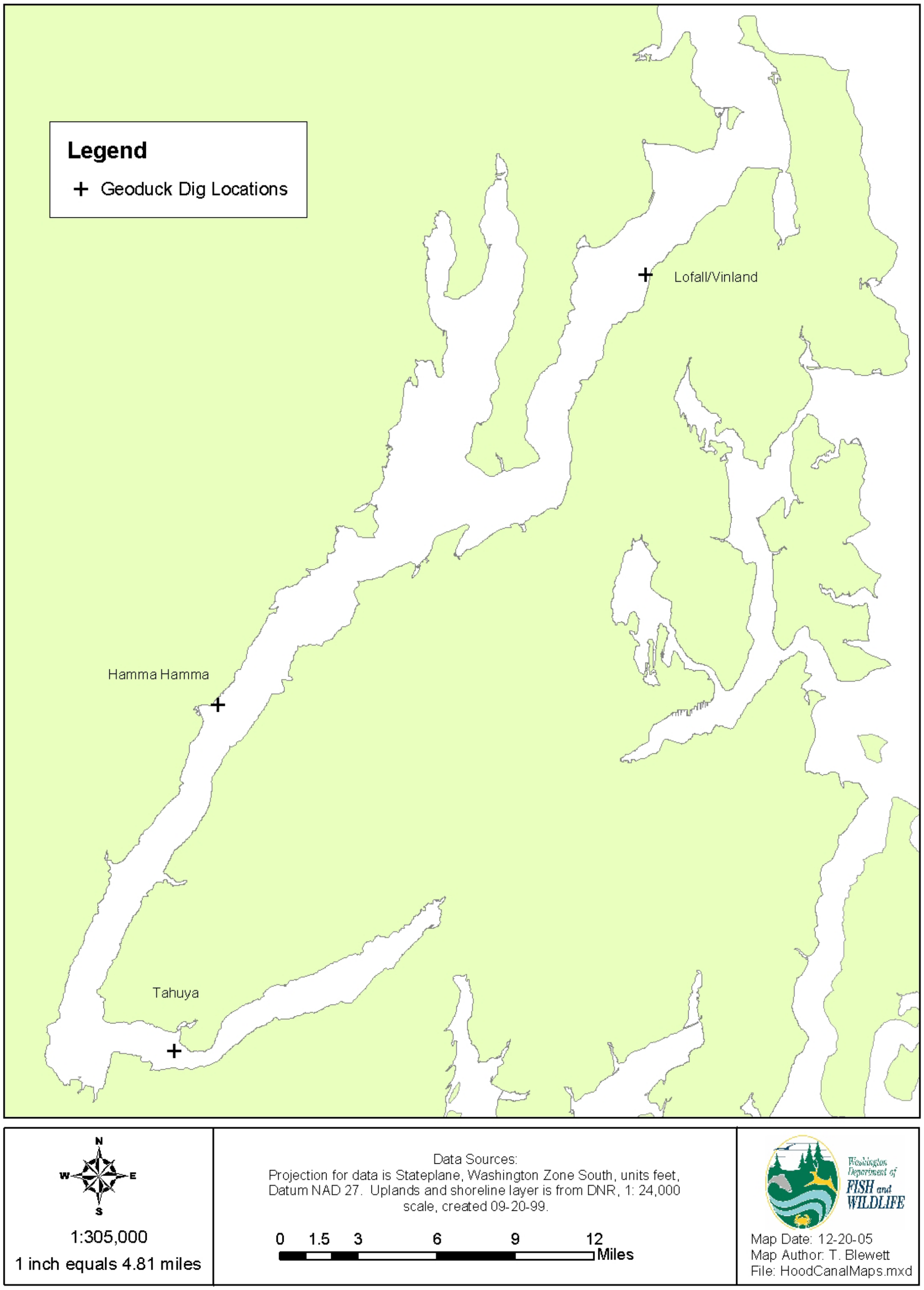


Figure 14. Between Lofall and Vinland Geoduck Tracts, 2005 Dig Station Locations

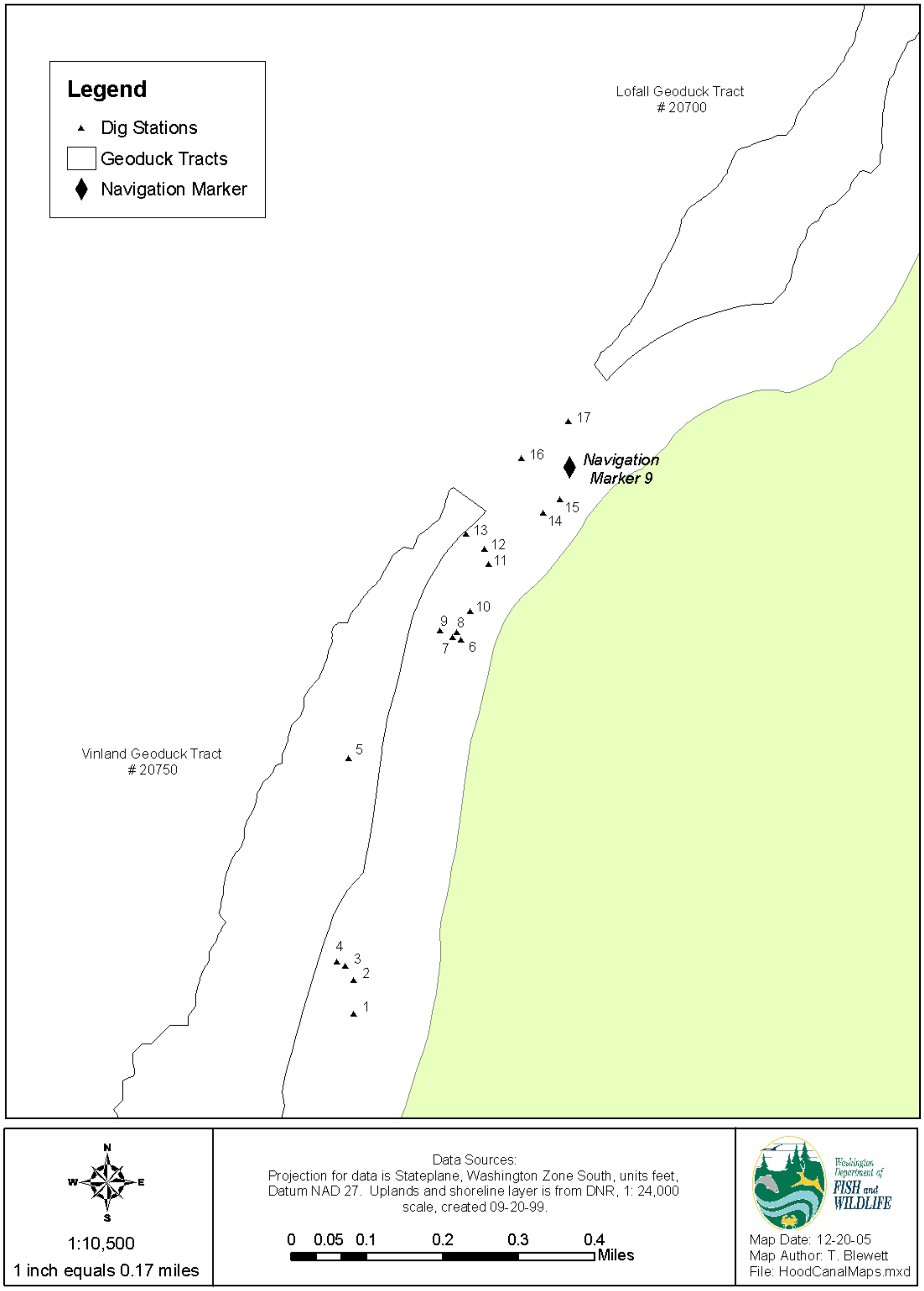


Figure 15. Hamma Hamma Geoduck Tract # 22850, 2005 Dig Station Locations

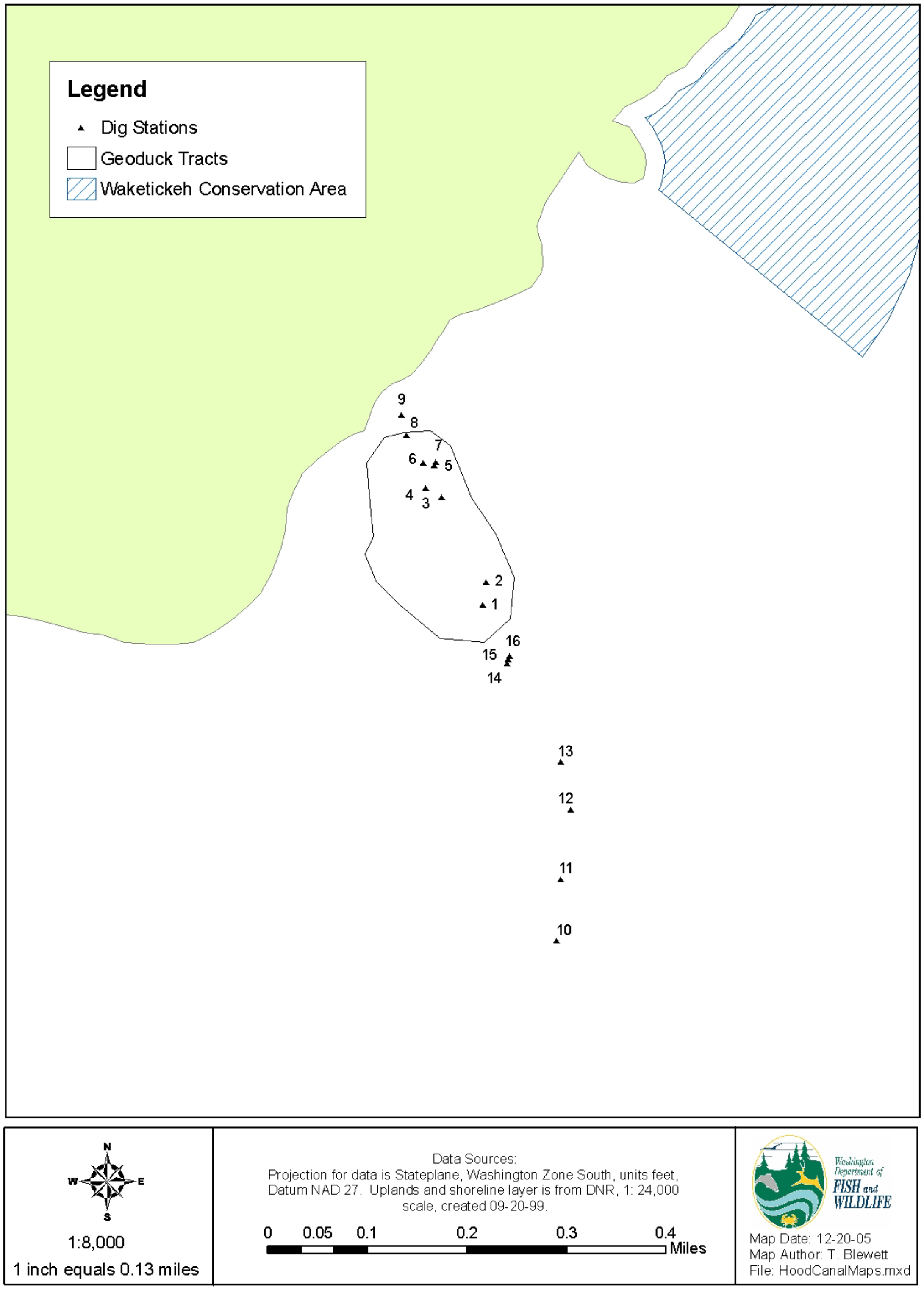
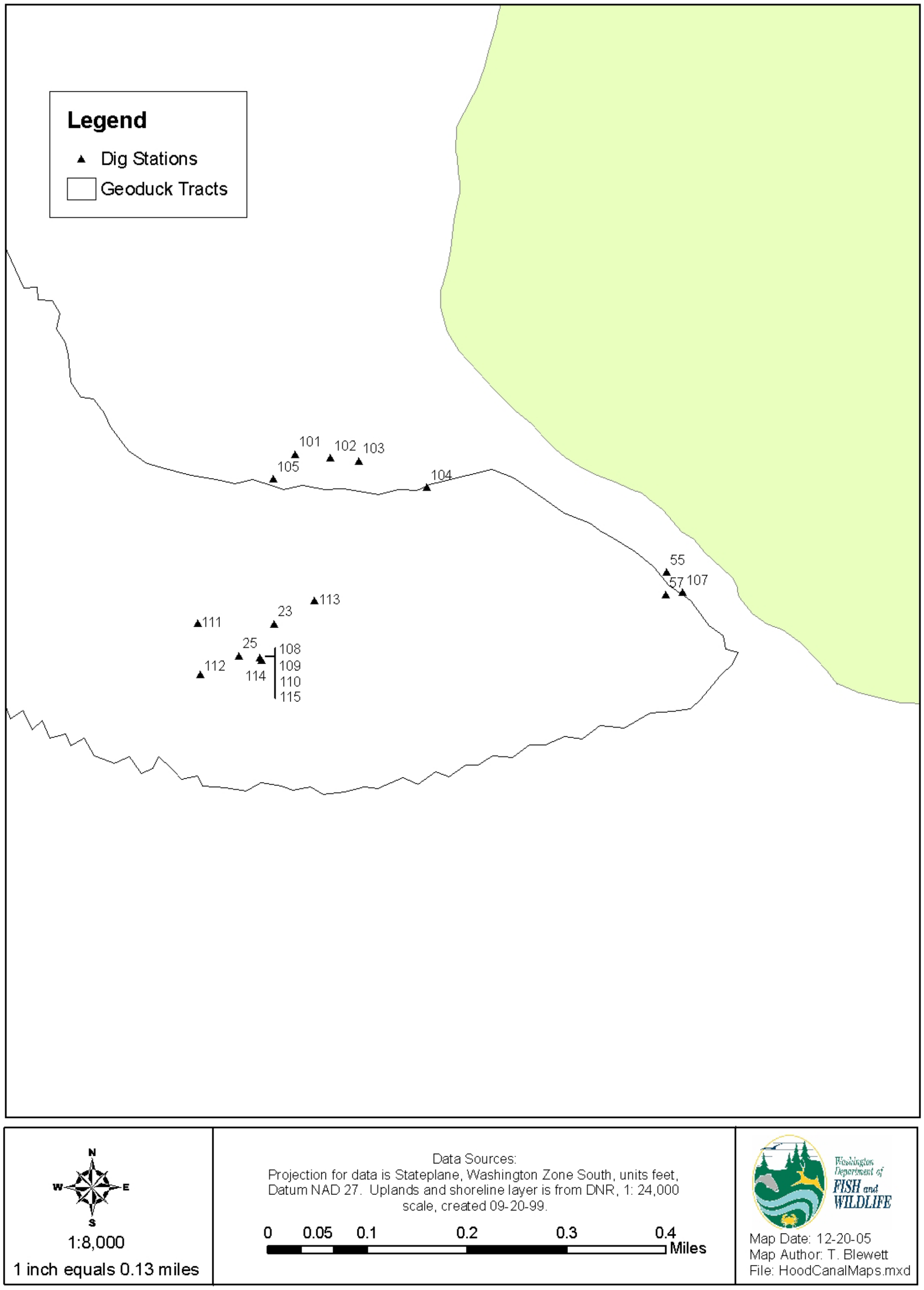


Figure 16. Tahuya Geoduck Tract # 23550, 2005 Dig Station Locations



7.0 LITERATURE CITED

Bradbury, A., Sizemore, B., Rothaus, D., and Ulrich, M. 2000. Stock Assessment of subtidal geoduck clams (*Panopea abrupta*) in Washington. WDFW Tech. Report (FPT00-01): 62 pp.

Johnson, O.W., Grant, W.S., Kope, R.G., Neely, K., Waknitz, F.W., and Waples, R.S. 1997. Status review of chum salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-32, 229 p.

Olah, A. 2001. Effects of ultraviolet radiation on distribution of the solitary ascidians, *Ciona savignyi*. Puget Sound Research 2001.

Roberts, M., Newton, J., and Hannafious, D. 2005. Quality Assurance Project Plan. Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study Year 1 Activities. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-114. www.ecy.wa.gov/biblio/0503114.html

Romanek, C.S., Jones, D.S., Williams, D.F., Krantz, D.E. and Radtke, R. Stable isotopic investigation of physiological and environmental changes recorded in shell carbonate from the giant clam, *Tridacna* maxima. Marine Biology 94; pp. 385-393 (1987).

Tukey, J.W. 1953. The problem of multiple comparisons. Department of Statistics, Princeton University. (unpublished)

Weidman, C.R., Jones, G.A., and Lohmann, K.C. 1994. The long-lived mollusk *Arctica islandica*: A new paleoceanographical tool for the reconstruction of bottom temperatures for the continental shelves of the North Atlantic Ocean. Jour. of Geophysical Resch., Vol. 99, No. C9. pp 18,305-18,314.

Zar, Jerrold H. 1999. Biostatistical Analysis (4th edition). Prentice Hall, Upper Saddle River, New Jersey, 663 pp.

8.0 GLOSSARY

Annuli	Growth increment in geoduck shell equivalent to one year of time
Bathymetry	The measurement of the depth of bodies of water.
Benthic	The bottom of a body of water, including the substrate.
Bioaccumulation	The accumulation of chemicals in the tissues of organisms. Generally the result of ingesting other organisms.
Bioconcentration	The concentration of chemicals within organisms at levels greater than those in the surrounding environment. Generally the result of processes such as respiration, feeding etc.
Commercial biomass	The estimated biomass on those tracts that are not polluted and are potentially available to be commercially harvested. (Tracts must receive a pre-fishing biological survey prior to harvest.)
Commercial geoduck	A geoduck in a commercial tract.
Commercial tract	A geoduck tract in which geoduck densities are considered high enough to support a fishery and which has no other drawbacks. The commercial status of tracts is listed annually in the Geoduck Atlas (Washington Department of Fish and Wildlife).
Dissolved oxygen	The amount of free oxygen dissolved in water or other liquids, usually expressed in milligrams per liter, parts per million, or percent of saturation.
Epibenthic	Organisms that live on the surface of the seabed
Epifauna	Animals that live on the surface of the seabed
Epiflora	Plants that are attached to the seabed
Euphotic	The zone of a body of water that receives sufficient light for plant to undergo photosynthesis.
Fines	Silt and clay less than 63 microns in size
Geoduck	A species of large burrowing saltwater clam (*Panopea abrupta*) native to the states of Washington and Alaska and the province of British Columbia, Canada

Geoduck Atlas	An annual Washington State Department of Fish and Wildlife publication listing all known geoduck tracts in Washington, along with maps of their location, the commercial status of the tract, estimates of geoduck biomass, and other summary information.
Geoduck tract	An area with defined boundaries that contain geoduck.
Harvestable geoduck	Geoduck large enough for the siphon or "show" to be seen by a diver.
Harvestable surplus	Term used to describe the assessed commercial fisheries stock available for harvest.
Hydrographic conditions	The physical characteristics of the earth's surface waters such as boundaries, currents and flows.
Infauna	Animals that live within the substrate of a body of water.
Intertidal	The zone between high and low tides, exposed and flooded by tidal fluctuations.
Isotope	One of two or more atoms having the same atomic number but different mass numbers.
Macroalgae	Multi-cellular algae with filamentous, sheet or mat-like morphology.
Management Region	A collection of commercially harvestable subtidal geoduck tracts along the Washington shoreline.
Mean High Water	The average height of the highest tides over a specific nineteen-year cycle.
Mean Lower Low Water (MLLW)	The average heights of the lowest tides observed over a specific nineteen-year cycle.
Meiofaunal	Infaunal animals that are retained on a 0.1-mm sieve mesh but pass through a 0.5-mm mesh or a 1.0-mm mesh
Micron	0.001 millimeter.
Nautical miles	1.15 statute miles.
Neritic	Associated with, or inhabiting, ocean waters between the low tide mark and a depth of about 600 feet.
Neustonic	Living in the surface layer of a water body.

Phytoplankton	Free-floating microscopic, unicellular plant organisms.
Pinnipeds	Seals, walruses, and similar animals with finlike flippers used for locomotion.
Piscivorous	Organisms that habitually eat fish.
Planktivorous	Organisms that habitually consume plankton.
Plankton	Typically small or microscopic plant and animal organisms that float or drift at or near the surface of bodies of water.
Puget Sound Treaty Tribes	Federally recognized tribes entitled to 50 percent of the harvestable surplus of fish and shellfish within Puget Sound. Members include the Jamestown S'Klallam Tribe, Lower Elwha Klallam Tribe, Lummi Nation, Makah Tribe, Muckleshoot Tribe, Nisqually Tribe, Nooksack Tribe, Port Gamble S'Klallam Tribe, Puyallup Tribe, Skokomish Tribe, Squaxin Island Tribe, Stillaguamish Tribe, Suquamish Tribe, Swinomish Tribal Community, Tulalip Tribes, and Upper Skagit Tribe.
Quota	The proportion of a resource that may be harvested during a defined time interval.
Rafeedie Decision	The 1994 United States Federal District Court Decision, presided over by Judge Edward Rafeedie, which affirmed tribal rights to harvest up to 50 percent of the shellfish on their usual and accustomed fishing grounds. There have been subsequent court rulings.
Recovery time	Estimated time for a commercially fished geoduck tract to return to its pre-fishing density.
Recruitment	The replenishment of a population of organisms through natural reproduction, settlement and growth processes.
Shellfish	For purposes of this text, a marine invertebrate with a soft unsegmented body usually enclosed in a shell.
Siphon	The tube shaped anatomical structure used by shellfish to take in water (incurrent siphon) and expel water (excurrent siphon).
Stable isotope	An **isotope** of an element that shows no tendency to undergo

	radioactive breakdown.
Sublittoral	Occurring below tidal ranges, but within the euphotic zone.
Subtidal	Marine and estuarine regions that are permanently covered by water.
Topography	The surface features of land (including submarine land).
Total Allowable Catch	The product of the estimated biomass of harvestable geoduck on commercial tracts and the recommended annual harvest rate.
Upwellings	A process in which cold, nutrient-rich waters from the depths of a water body rise to the surface.
Valve	A geoduck valve is the shell of the geoduck clam
Zooplankton	Typically small or microscopic, free floating animals.